INSTANCE THEORY OF AUTOMATIZATION EFFICACY OF TWO
REHEARSAL STRATEGIES ON RETRIEVAL
OF BASIC SUBTRACTION FACTS

By

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract of Dissertation Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

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The purposes of this study were to test the validity of an instance theory of automatization on a meaningful educational task and to investigate the efficacy of oral and written rehearsal strategies on retrieval of information. A concrete task, knowledge of basic subtraction facts, was used and tested on a group of six middle school students with math disabilities based in a school environment. A single subject comparison of treatment design was used. Analyses of data evaluating short-term retrieval indicate that oral rehearsal produced more positive effects than written rehearsal. Analyses of data evaluating long-term retrieval indicate that oral rehearsal produced greater effects for five of the six participants although magnitude of effect varied across participants. For the six participants in this study, oral and written rehearsals were effective strategies for decreasing timed response rates on groups of subtraction facts. Both rehearsal strategies produced similar patterns of performance for most participants.

Also of interest was the relationship of stated preference to performance. Two participants preferred oral rehearsal; three participants did not prefer one strategy to the other; and one participant preferred written rehearsal. For five of the six participants analyses of performance supported preference.

CHAPTER 1
INTRODUCTION

In a time of electronic assistance and access to technological programs some people question the utility of teaching computational skills in the schools Even though computers and calculators are rapidly changing the way most people deal with arithmetical situations instruction in computational skills is still an educationally sound practice for several reasons A learner s skill in mathematical computation facilitates learning of subsequent related topics. It frees individuals from dependence on others or on mechanical devices Computational skills build a base for future learning of mathematical content by making it easier for the learner to focus on the process of problem solving rather than on computing. Pupils must understand both the meaning and the significance of arithmetic operations and apply these operations Computational skills are a vital component of a mathematics curriculum and are a required functional life skill

The traditional educational approach to the teaching of mathematics is one that introduces a broad range of skills and knowledge In the percentage correct, mastery approach of teaching mathematics, most instructional time is committed to acquisition or establishment of skills. Johnson and Layng (1994) reported that 70% of instructional time is allotted to establishment of skills 20% to practice of skills and 10% to assessment.

Reliance on percentage correct measures as the basis of success in a mathematics curriculum raises numerous educational concerns. Accuracy alone cannot adequately measure success within a curriculum. Accuracy cannot measure improvement beyond 100% correct.

A student's level of fluency is a critical component of mastery. All students who perform at the same level of accuracy are not equally skilled. Lindsley (1990) remarked "The time honored educational measure of academic work—percentage correct—produces highly accurate, but painfully slow, learners" (p. 10).

Accuracy, unlike fluency, rarely predicts whether performance will be retained, transferred, or combined with other skills. Proponents of fluency-based instruction point to the positive results of fluency training in four areas of instruction: (a) fluency increases the retention of knowledge, (b) fluency increases on task behavior, thus increasing the amount of instructional time available to the student, (c) fluency supports more rapid learning of composite skills, and (d) fluency often produces composite skills with virtually no formal instruction. Children who are dysfluent in basic skills cannot progress successively within a mathematics curriculum (Haughton, 1972).

Fluency in computational skills received major emphasis by the National Council of Teachers of Mathematics (NCTM) in Principles and Standards for School Mathematics (2000). The need for computational fluency for elementary-aged students was strongly supported in the document. The NCTM recommended that all students in PreK-2 develop fluency in addition and subtraction facts through 10. All students in grades 3 through 5 should develop fluency in addition and subtraction facts through 18 and multiplication and division facts through 81.

In acquisition of addition and subtraction knowledge children use three distinct developmentally sequenced strategy phases. Children employ (a) a direct modeling strategy in which numbers are represented using physical objects or fingers and all numbers are represented with an equal numbers of objects (b) a counting strategy when counting begins with the first number or second number and the child counts up in addition and up or down in subtraction, and (c) a number fact or derived fact strategy where the answer is recalled from memory with no apparent counting involved. Researchers discovered that children's use of strategies is a highly variable phenomenon. Children often use them interchangeably invent them even if taught a different one and fall back on the use of inefficient strategies if manipulatives or number lines are made available (Carpenter & Moser 1984 Woods Resnick, & Groen, 1975).

Memory research using rehearsal strategies has added to knowledge of children's acquisition of skills. Although results with elementary-aged children were mixed concerning issues of retention and generalization the majority of studies clearly demonstrated that rehearsal strategies such as practice categorizing and sorting were effective instructional tools for young students (Asarnow & Meichenbaum, 1979 Lange & Pierce, 1992).

Depending on memory model, rehearsal strategies have different functions in the transfer of data to long term storage. The most commonly accepted memory model is the information processing model typified by Atkinson and Shiffrin (1968) and Gagné (1985). In information processing models rehearsal strategies are viewed as an encoding function that transfers information from short term to long term memory. According to

information processing theorists automaticity (fluency) in math facts is achieved through deeper and more meaningful encoding.

Logan (1988) challenged the information processing theory. In Logan's memory as-attention theory, rehearsal strategies are viewed as repeated instances of knowledge that are encoded and retrieved as obligatory consequences of attention. Automaticity (fluency) in math facts is achieved when enough instances are in memory to permit declarative performance (memory-based) over procedural performance (algorithm based). Logan's instance theory of automatization offers a mechanism by which to investigate rehearsal strategies related to retrieval of math facts. Instance theory is designed to explain single-step direct-access retrieval that characterizes basic math facts. Logan's memory theory was tested using pseudo-arithmetic memory tasks with adults and presents plausible explanations for academic progress, memory, and fluency. Logan's theory provides a mechanism by which learning can be better understood and intervention strategies developed for retrieval of basic math facts.

Statement of the Problem

A student's success within a mathematics curriculum is dependent on automaticity or fluency of computational skills. Positive effects of fluency training on instructional outcomes are well documented. Young children can improve performance using rehearsal strategies.

There is a paucity of research on rehearsal strategies which enhance performance on single-step, direct-access retrieval tasks that characterize memory of basic math facts. Furthermore, memory and rehearsal strategy research agendas have not been extended to (a) educationally meaningful tasks to test both memory theory and learning processes, (b)

children s retrieval of basic facts and skills and (c) children who exhibit a learning disability in mathematics

The purposes of the study were two fold First the study proposed to test the validity of an instance theory of automatization on a meaningful educational task with children who exhibit a learning disability in mathematics in a school environment Second the study proposed to investigate the efficacy of oral and written rehearsal strategies related to retrieval of basic subtraction facts by middle school students exhibiting a learning disability in mathematics.

Purpose of the Study

The purpose of the study was to test the validity of an instance theory of automatization by investigating the effects of two rehearsal strategies on retrieval of basic subtraction facts by middle school students with math disabilities The following questions were addressed in the study

Q1 What is the efficacy of two rehearsal strategies on retrieval of basic subtraction facts?

(a) What is the effect of oral rehearsal on oral fluency?
(b) What is the effect of oral rehearsal on written fluency?
(c) What is the effect of written rehearsal on oral fluency?
(d) What is the effect of written rehearsal on written fluency?

Q2 Given the four conditions stated above is oral or written rehearsal a more effective strategy?

Q3 Do treatment effects maintain over time in terms of rate and accuracy?

Q4 Is there a relationship between a participant's preferred rehearsal strategy and performance?

Rationale of the Study

Several studies provided evidence for the need to develop instructional programs to increase computational fluency with basic math facts. In a 3-year longitudinal study of acquisition of addition and subtraction concepts with 88 children as they progressed through grades 1 through 3, Carpenter and Moser (1984) reported disturbing data on mastery of math facts. Eleven percent of the children at the end of first grade had demonstrated mastery of facts fewer than 10. Forty five percent of the same students at the end of second grade had mastered facts fewer than 10. Twenty four percent had mastered facts greater than 10. By the middle of the third grade, 89% of the students had mastered facts fewer than 10, and 70% had mastered facts through 18.

The National Center for Educational Statistics (NCES) reported results of a national assessment in mathematics for students in grades 4, 8, and 12. In 1996, 38% of fourth graders performed at or below the Basic Level in mathematics (NAEP, 1996).

The Alachua County Curriculum-Based Assessment Project (1996) included performance data of basic fact probes given to students in grades 1 through 5. The written subtraction rates of digits per minute were 6, 12, 15, and 18 for grades 1, 2, 3, and 4, respectively. Of particular interest is the rate of digits per minute for division skills (two digits divided by one digit) in fourth grade. The division skill tested in fourth grade is an example of a composite skill, i.e., division requires the prerequisite skills of multiplication and subtraction. The mean score of 10 digits per minute for division problems for fourth graders indicates cumulative dysfluency. When basic skills are not taught to fluency criteria, overlapping dysfluent skills prevent success with composite skills presented later in a mathematics curriculum.

Researchers have demonstrated that automatic or fluent, performance of basic math facts is a determiner of success within a mathematics curriculum Practice or rehearsal strategies produced positive effects with students of all ages Practitioners need research-based best practices in fluency building that can be successfully incorporated within existing mathematics curricula. At this time there are empirical data to support written practice as an effective strategy to improve performance in basic math facts, but there is little evidence that other strategies have been attempted or validated There are no studies that compare the efficacy of written practice to other practice strategies

In addition, there are few studies that have examined the effectiveness of rehearsal strategies on single-step memory retrieval of facts such as basic facts There are no studies on oral practice as an instructional intervention, even though oral practice is certainly a common form of rehearsal for students and adults There is only one study (Friedrich, 1974) that included participants identified as slow learners Examinations of other rehearsal strategies specifically oral practice strategies, could lead to more successful and efficient educational interventions for fluency in basic math facts and could expand knowledge of successful rehearsal strategies in mathematics for children with disabilities

Definitions of Terms

An algorithm refers to procedural knowledge in problem solving i e a specific strategy used to solve a problem (Ashcraft, 1982, Anderson, 1995)

Asymptote refers to the minimum time required to perceive the stimuli and emit a response (Logan, 1988)

Automaticity refers to behavior that can be performed without engaging the cognitive system. It is effortless performance characterized by accuracy and speed (Binder, 1996; Johnson & Layng, 1994). Automaticity refers to a response without hesitation.

Basic subtraction fact refers to a subtraction problem in which the minuend does not exceed 18 and the subtrahend does not exceed 9.

Decrementing refers to a strategy of counting down from a given number to reach a solution (Woods, Resnick, & Groen, 1975).

Encoding refers to the process of creating a long-term memory record to store an experience (Anderson, 1995).

Fluency refers to the automatic performance of a skill (Binder, 1993).

Heuristics refers to problem solving along empirical lines, using rules of thumb to find solutions or answers (Webster's New World Dictionary of the American Language, 1980).

Incrementing refers to a strategy of counting forward from a given number to reach a solution (Woods, Resnick, & Groen, 1975).

Initial tool skill refers to initial response rates for reading and writing numbers.

Long-term effect refers to analyses of data collected 2 weeks after completion of all phases of the study.

Priming refers to a process by which a prior exposure makes a memory more available or facilitates the perceptual processing of an item (Anderson, 1995).

Rehearsal refers to a process of repeating information to oneself to help remember the information (Anderson, 1995).

Rehearsal session refers to oral and written responses to 10 subtraction facts.

Short term effect refers to analyses of data collected immediately after completion of rehearsal sessions in each phase of the study.

Stroop effect refers to a process by which attention to an item activates associations in memory that interfere with processing of an item (Anderson, 1995; Logan, 1988).

Delimitations

The investigation had five delimitations. First, the investigation was restricted geographically to Alachua County, Florida. Second, it included only middle-school-aged children. Third, participants were students with learning disabilities in mathematics who were served for part of the school day in a special education program. Fourth, the investigator provided all instruction and feedback. Fifth, retrieval of subtraction facts was the only mathematical operation under investigation.

Limitations

There were several limitations concerning the generalization of results. First, the results were limited by subject selection. Caution should be exercised in extending the findings to students in other grade levels, settings, or disability categories. Second, the results focused on one mathematical skill. Generalization to other mathematical operations cannot be inferred. Third, the data may be interpreted as a function of one behavior change agent. Generalization of results to other subjects, settings, instructional personnel, and skills will require further investigation. Finally, the investigator assumed that there was no generalization from one condition to the next.

Summary and Overview

Today s educators are being held increasingly accountable for student progress as measured by performance on standardized achievement tests In many states school ratings and additional monies are linked to yearly improvement in student achievement test scores

In the area of mathematics many local state and national education agencies are reporting performance deficits in the area of computation by students in elementary and secondary settings Proponents of fluency training suggest that traditional accuracy based criteria used in most mathematics curricula may be a contributing factor to dysfluency reported by education agencies (Lindsley 1990)

Researchers have demonstrated that rehearsal strategies that build skills to fluency criteria increase academic performance and are effective with children (Binder 1996 Pollard 1979) Fluency-building strategies produce several positive educational outcomes. Fluency building improves retention, increases on-task behavior and supports a more rapid learning of higher level skills (Johnson & Layng 1994)

There are however gaps in the research concerning the effectiveness of rehearsal strategies First, in the area of computational skills written practice is the only rehearsal strategy empirically validated The effectiveness of other rehearsal strategies, such as oral practice has not been investigated Second the memory and rehearsal strategy researchers have not included participants from at risk remedial or disability populations in investigations The effectiveness of different rehearsal strategies with students with learning disabilities is unknown.

The purpose of this study was to examine the effectiveness of oral and written rehearsal strategies on retrieval of basic subtraction facts by middle school students who exhibit a learning disability in mathematics. In Chapter 2, a review of Logan's (1988) instance theory of automatization is presented as the theoretical framework in which to examine the efficacy of two rehearsal strategies. A brief overview of memory theories provides an historical perspective for introducing Logan's instance theory. An analysis of the literature as it relates to instruction strategies for increasing memory and computational skills is included. Finally, a rationale for single subject methodology is presented.

CHAPTER 2
REVIEW OF LITERATURE

Literature from multiple disciplines guided the design and evaluation of two rehearsal strategies concerning retrieval of basic subtraction facts. In Chapter 2 relevant literature pertaining to mathematics instruction, fluency-based training, and memory-rehearsal strategies is summarized. Logan's (1988) instance theory of automatization and subsequent research with pseudo-mathematic memory tasks are included. A rationale for use of single subject design is presented.

First, a summary of strategy use by children in solving addition and subtraction is presented along with related research. A model of mental arithmetic is explained. Second, principles of fluency-based training are included. Research on model programs and implications for instruction are discussed. Third, an analysis of research on rehearsal strategies with children is presented. Teaching strategies, as well as a teacher's role in strategy development, drill, and effective practice are summarized. Fourth, Logan's (1988) instance theory of automatization as it relates to automaticity of performance is presented. Included is a brief historical review of several memory models and theories. The use of Logan's instance theory and its relation to mathematics instruction are discussed. Finally, a rationale for using single subject research design is presented.

Strategy Use

Numerous researchers investigated the processes used by children in solving simple addition and subtraction problems. In the research a variety of simple counting models were used, many of which included a counter that performed two operations: (a) setting to a value and (b) incrementing by one. Other researchers used manipulatives or allowed children to use fingers (Ashcraft & Fierman, 1982; Carpenter & Moser, 1984; Groen & Parkman, 1972; Woods, Resnick, & Groen, 1975).

Regardless of counting model, addition and subtraction strategies include three different phases: (a) direct modeling, (b) counting, and (c) number facts. Table 2.1 summarizes the addition and subtraction strategies (Carpenter & Moser, 1984).

Research on Strategy Use

Groen and Parkman (1972) observed 37 first grade children on choice of strategy with a simple addition problem with a sum less than 10. Over half of the students (20 out of 37) used a *counting on from larger* strategy to solve addition problems.

Woods, Resnick, and Groen (1975) tested five processes used by children in solving single-digit subtraction problems. Forty participants in grade 2 and 20 participants in grade 4 performed subtraction problems. All fourth graders and most second graders used a strategy which involved incrementing or decrementing, whichever one was faster.

Carpenter and Moser (1984) investigated major stages in the development of addition and subtraction concepts and skills. Specifically, they cataloged changes from one strategy to another as children progressed through school. Carpenter and Moser

Table 2-1

Addition and Subtraction Strategies

Addition Strategies	
Direct modeling strategy	
Counting all	Both sets are represented using physical objects or fingers and the union of the two sets is counted
Counting strategies	
Counting on from first	Begins with first number given and continues the number of units represented by the second number
Counting on from larger	Begins with the larger number given and continues the number of units represented by the smaller number
Number fact strategies	
Recall	The fact is immediately recalled with no apparent counting
Derived facts	The number fact is derived from a recalled number fact
Subtraction Strategies	
Direct modeling strategies	
Separating from	A set of *a* elements is constructed, *b* elements are removed
Adding on	A set of *b* elements is constructed, elements are added until there is a total of *a* elements. The answer is the number of elements added
Matching	A set of *a* elements and *b* elements are matched one to one. The answer is the number of elements left over
Counting strategies	
Counting down from	Starting with *a*, counting downward to *b* amount. The last number is the answer
Counting up from given	Starting with *a*, counting forward until reaching *b*. The answer is the number of counts
Number fact strategies	
Recall	The fact is immediately recalled with no apparent counting
Derived facts	The number fact is derived from a recalled number fact

followed 88 children from grade 1 through grade 3 and interviewed them about strategy choice three times per year during the first and second grades and twice in third grade Results of the study include the following

1 In solving addition problems, children initially solved a problem using a *counting all* strategy, and this strategy gradually gave way to *counting on* and the use of *number facts* Eighty percent of participants displayed multiple strategy use

2. In subtraction, children almost exclusively used modeling and counting strategies that reflected the additive action of the problem As with addition children initially used manipulatives to model the problem Children used an *adding on* strategy which was later replaced by a more efficient *counting up from given* strategy

Children tended to avoid a *counting down from* strategy in subtraction. Eighteen percent of the subjects never counted down 45% counted down only once in any given interview and only 6% counted down three or more times in any interview *Counting down* appeared only after *counting up from given* had emerged first.

3 Eleven percent of the children mastered facts through 9 by the third interview (end of first grade) By mid-second grade 45% mastered facts through 9 and 24% mastered facts through 18 By the middle of third grade 89% mastered facts through 9 and 70% mastered facts through 18

Children learned a number of fact combinations earlier than others such as doubles (e g 4 + 4) Some children used a small set of memorized facts to derive solutions for addition and subtraction problems involving other number combinations The solutions usually were based on doubles or numbers whose sum is 10

4. *Derived facts* were used for subtraction problems. Many of the *derived facts* were based on addition. Children explained that subtraction facts learned at a *recall* level were the result of addition facts. For example, children knew the answer to 13 - 7 because they knew that 7 + 6 = 13. Over 80% of the students used *derived facts* at some time during the study.

Children used multiple strategies to solve addition and subtraction problems and usually employed strategies that solved problems in the least amount of time. There was significant variability in the development of strategy use by children in the early elementary grades.

A Model of Mental Arithmetic

Ashcraft (1982) proposed a composite model of mental arithmetic. The model includes an initial encoding stage, during which perception and translation of the problem into a useable mental code is accomplished. Following encoding, the search/compute stage involves the actual arithmetic component of performance. The search/compute stage is composed of two components identified as procedural or declarative. The procedural component consists of a person's general knowledge about arithmetic and includes algorithms, heuristics, rules, counting, and informal idiosyncratic procedures. The declarative component consists of stored facts.

The search/compute stage is followed by a decision stage. During the decision stage, a person relies on number line concepts to justify an answer. The decision stage is followed by the response stage.

A young child solves numerical problems by means of counting strategies. Response time to a simple addition problem would be the length of time a child needed to

access the procedural counting strategy and return a decision to the response generator. As children get older and memorize more facts, the declarative component speeds up the search/compute stage and returns a faster decision.

The model includes two major components of arithmetic knowledge: (a) procedural knowledge about arithmetic and (b) declarative knowledge of stored facts. Procedural knowledge has two functions. It may guide fact retrieval, or it may substitute for declarative knowledge of math facts. In certain circumstances, one of these two major components is isolated as the source of performance. For example, when adults perform simple addition or multiplication, they access declarative knowledge in the search/compute stage. In contrast, when first graders perform simple addition, they access procedural knowledge of counting in the search/compute stage. For older children, the search/compute stage will access different combinations of both components.

Fluency-Based Instruction

Principles of Fluency-Based Instruction

Fluency is defined in the literature as rate of performance that makes skills not only useful in everyday affairs but also remembered even after a significant period of no practice (Binder, 1987; Haughton, 1972). Accurate performance needs to become quick, easy, and automatic to be useful, remembered, and applied (Johnson & Layng, 1992).

According to Miller and Heward (1992), there are several important reasons why measures of fluency should be part of a student's performance assessment. First, fluency provides a more complete picture of learning and performance. Accuracy measures provide only information on the correctness of performance, whereas rate of response

gives a precise indication of the accuracy of performance in relation to the amount of time required for response. Second, rate per minute is a more sensitive measure of change in performance than an accuracy measure alone. Third, fluency has functional implications for in-school and out-of-school performance. For example, speed and accuracy are necessary components for performance on timed, standardized tests as well as performance in everyday computations while shopping.

Binder (1993) outlined critical elements in a fluency-based approach to instruction. Fluency instruction provides a systematic methodology for implementing effective practice strategies. First, measurement of any skill must include accuracy of response within a time dimension. Second, instructional procedures must provide sufficient practice and allow a student to progress at his own pace. Third, instructional materials must contain many examples and items to practice and must be easy to use. Fourth, the critical steps, or prerequisites, of composite skills must be taught to fluency before introduction of the composite skill.

Proponents of fluency-based training refer to this approach as generative instruction. Generative instruction focuses on effective teaching to establish fluency of key component skills and their underlying tool elements. When presented with new learning situations, academic behaviors can recombine in new ways that correspond to higher level complex skills. For example, basic number writing, addition, subtraction and multiplication skills are prerequisite skills that must be fluent in order to successfully factor an equation (Johnson & Layng, 1992).

Model Programs

During the 1970s the Precision Teaching Project in Great Falls Montana added 20 to 30 minutes per day of timed practice to the academic program in several public schools Over a period of 3 years average performance on the Iowa Test of Basic Skills (ITBS) rose between 20 and 41 percentile points (Beck, 1979 Beck & Clement, 1991) Results were obtained at a cost of a few hundred dollars per teacher for training and $10 per student per year for supplies

The Morningside Academy in Seattle, Washington combined the instructional practices of direct instruction and precision teaching for over a decade emphasizing fluency for each step in its curriculum Children and adolescents in the program gained an average of almost three grade levels per year as measured by standardized tests (Binder 1993)

Morningside Academy staff directed an adult literacy project funded by the Job Training and Partnership Act (JTPA) in 1987 The 32 participants' ages ranged from 16 through 26 Entering skills in reading, math, and writing ranged from second to eighth grade level Participants attended the fluency based program 5 days per week for 2 hours per day Two skill areas were taught each day Twenty nine of 32 participants exited the program at or above the national eighth grade level literacy standard Average progress was 1 7 grade levels per 20 hours of instruction or two grade levels per 24 hours of instruction (Johnson & Layng 1992)

In 1988 Morningside Academy personnel trained 20 Asian-American women, ages 25 to 40 in skills necessary for successful entry into office and computer related training programs. Nineteen successfully completed the program with each academic

skill averaging a gain of 2.1 grade levels per month or two grade levels on the Metropolitan Achievement Test (MAT6) per 19 hours of fluency training (Johnson & Layng, 1992)

Johnson and Layng (1992) reported on a 6-week summer program at Malcolm X College in Chicago that targeted prospective college students whose math skills were deficient. Thirty-three students, ages 19 to 48, attended fluency-based instruction 4 days per week for 3 hours in the morning. The researchers divided participants into five instructional groups. Two groups received instruction on whole number operations. Two groups received instruction with fractions. One group, the advanced group, reviewed high school math skills. The two whole number groups, with entering fourth-grade level skills, gained 1 year in math computation and 0.9 years growth in problem solving on the MAT6. The two fraction groups, with entering fifth-grade level skills, gained 6 years in mathematics computation and 2 years growth in problem solving on the MAT6. The advanced group, with entering skills near the 10th-grade level, gained 1.9 years in math computation and 3 years in problem solving on the MAT6. Malcolm X College used this pilot program to establish the Precollege Institute in 1991 for prospective college students with reading and math skills below sixth grade level. Johnson and Layng reported an average increase of two grade levels per skill per 20 hours of fluency training.

Fluency-Based Outcomes on Instructional Variables

Researchers have reported the success of fluency-based interventions and programs for 30 years. Binder (1996) suggested that the positive results of fluency-based training could be summarized in three instructional outcomes: (a) fluency increases retention and maintenance of knowledge (Berquam, 1981; Kelly, 1996; Orgel, 1984;

Pollard, 1979 Solsten & McManus 1979) (b) fluency increases on task performance or task endurance (Binder, 1984 Binder Haughton, & Van Eyk, 1990 Cohen Gentry, Hulten, & Martin 1972 LaBerge & Samuels, 1974) and (c) fluency increases the ability to apply adapt, or combine knowledge to new skill situations with general or mild disability populations (Beck, 1979 Evans & Evans, 1985 Johnson & Layng 1992 Lindsley 1992, Maloney Desjardins, & Broad, 1990 Mercer Mercer & Evans 1982 Starlin, 1972, Van Houten, 1980) and severe populations (Binder 1976 1979 Pollard 1979 Solsten & McManus, 1979)

Implications for Instruction

According to proponents of fluency-based training the result of instruction is either cumulative dysfluency or contingency adduction. Cumulative dysfluency and contingency adduction are educationally opposite consequences of instruction

Cumulative dysfluency is the result of progression within a curriculum when prerequisite skills are not taught to fluent levels   Performances with fluency deficits despite their accuracy accumulate in a curriculum sequence   Prerequisite knowledge that is not learned to the appropriate level of fluency can retard development of subsequent skills or knowledge   For example, when basic computational facts are accurate but not fluent, students cannot keep up with demonstrations of complex problem solving (Binder 1993)   Accumulation of dysfluent skills limits acquisition of composites that depend on them   Numerous researchers believe that cumulative dysfluency is the single most important factor in long-term student failure (Binder, 1988 Johnson & Layng, 1992 Pennypacker & Binder 1992)

In contrast, contingency adduction aids in the development of composite skills. When students attain fluency levels in component skills, less instruction in composite skills is required. As students move up a curriculum sequence, learning appears to get easier as subject matter gets more complex, and sometimes learning of composite skills occurs with little or no formal instruction (Johnson & Layng, 1992, 1994, 1996).

Implications for Math Instruction

Researchers operationalized fluency in mathematics instruction as written digits per minute with error rate. Several groups of researchers suggested written proficiency rates for basic math facts. In the 1970s, The Precision Teaching Project set rates of 70-90 digits per minute for addition, subtraction, multiplication, and division facts. Starlin and Starlin (1973) proposed 20-30 digits per minute with 0-2 errors for addition to 9 and subtraction from 9. Rates for addition to 18, subtraction from 18, and multiplication and division facts were 40-60 digits per minute with 0-2 errors. Although Haughton (1972) first set rates for all facts at 40-50 answers per minute, he later increased the written rate for all facts to 80-100 digits per minute.

In the 1980s and 1990s, other researchers proposed fluency rates for written answers to basic math facts. Koenig and Kunzelmann (1980) set rates of 60 digits per minute for addition to 9 and subtraction from 9. Subtractions from 18 and multiplication facts to 81 were set at 90 written digits per minute, and division of facts to 81 was set at 60 written digits per minute. Smith and Lovett (1982) suggested written rates of 50 and 40 digits per minute for addition to 9 and subtraction from 9, respectively. Multiplication rates were set at 50 per minute and division rates were set at 45 per minute. Although Howell and Morehead (1987) did not specify grade levels, they set fluency rates of 40

facts per minute for oral and written facts. Johnson and Layng (1992) proposed a written rate of 80-100 digits per minute for all basic fact combinations.

Fluency building instruction is beneficial to acquisition of basic mathematical skills and aids in acquisition of higher level composite skills. There is significant variability in proposed fluency rates for written answers to basic fact operations. Only one research effort has included written and oral rates of fluency to basic facts (Howell & Morehead, 1987).

Rehearsal Strategies

Howard (1995) summarized research on learning and memory as it related to children and strategy development. Strategies greatly improve performance. Children acquire more strategies as they get older, and they become more adept at choosing the best one for a task. Children continually learn new strategies and vary usage of ones that they know. With age, they need fewer hints to (a) process or form better ones and (b) improve component processes such as encoding, mapping and inference making. Older children are more likely to generalize strategies beyond training stimuli and try additional ones when their initial strategy does not work well. Children also become more metacognitive with age; that is, they learn more about how their memory works.

Rehearsal Strategies with Young Children

Young children can be taught rehearsal strategies that improve performance. Mere practice at a task increased performance of kindergarten children on serial recall tasks (Asarnow & Meichenbaum, 1979). Lange and Pierce (1992) taught 4- or 5-year-old children multiple strategies of study sorting, group naming, and self-cuing, which

produced increases in performance on posttest tasks 3 days later. Paris, Newman, and McVey (1982) taught 7- and 8-year-old children multiple strategies of sorting, labeling, blocked recall, self-testing, and cumulative rehearsal with significant results in the areas of recall, clustering, and sorting. Cumulative rehearsing (i.e., rehearsing an item and all preceding items) for first graders improved performance in serial recall tasks (Gruenenfelder & Borkowski, 1975). Other researchers found that knowledge of the value of the strategy and/or instruction of a strategy with feedback significantly improved performance with children ages 4 through 7 (Kennedy & Miller, 1976; Lacher, 1983; Lange & Pierce, 1992; Paris, Newman, & McVey, 1982).

Additional researchers have compared the effects of specific manipulations of single and multiple rehearsal strategies on recall tasks of children in kindergarten through third grade. Dick and Engle (1984) instructed second graders on three rehearsal strategies to test effectiveness of individual item encoding versus inter relatedness of item encoding. The researchers modeled semantic, relational, and elaborative strategies. Second graders who received semantic and relational strategy training had higher generalization scores. Kurtz and Borkowski (1984) demonstrated that a combination of metacognitive training and strategy training produced superior results in strategy use and recall by first- and third grade children. Ornstein, Medlin, Stone, and Naus (1985) found that when second graders and sixth graders manipulated access to previously viewed items, use of rehearsal strategies and recall increased for second grade participants.

When temporal sequences in rehearsal strategies are manipulated, children in kindergarten, first, and third grades increased use of rehearsal strategy. McGilly and Siegler (1989) provided 5-second and 15-second delays between stimuli and response on

recall of number lists with kindergarten, first, and third graders. With the longer time delay, use of strategy increased as well as accuracy of responses for all age groups. Although repeated rehearsal differed initially by grade, children in all age groups switched to repeated rehearsal strategy if feedback on responses was negative. Frank and Rabinovitch (1974) confirmed that spontaneous rehearsal on auditory memory tasks is operative by the third grade, and results were consistent with previous experiments with visual memory tasks.

In a study of rehearsal strategies across different ability levels within the same grade, Friedrich (1974) compared concrete versus abstract strategy training with pacing of stimuli by slow, average, and gifted third graders. Concrete strategy training involves the use of concrete nouns (i.e., animals, vegetables) to categorize items. Abstract strategy training involves the use of higher order collective nouns (i.e., transportation, hobbies) to group items. Self-pacing produced better recall than experimenter-pacing, and concrete strategy training produced better recall than abstract strategy training for all ability groups.

Although young children are able to improve performance with rehearsal strategies, there is little evidence to suggest that young children maintain rehearsal strategies or generalize them to later opportunities. After 1 week, Gruenenfelder and Borkowski (1975) found that 35% of the students could not transfer a learned strategy to a new situation. Other researchers found that 4- through 6-year-old children used little or no transfer on tasks presented 3 or 7 days later (Lacher, 1983; Lange & Pierce, 1992).

Age-Related Differences in Recall

Summaries of studies in the area of memory development consistently include findings of large age-related differences in recall. There are two plausible explanations for this phenomenon. The first is that age differences in recall are attributed to the fact that children younger than 8 years typically do not spontaneously employ organizational strategies while between age 8 years and adulthood, there is a clear developmental increase in the use of such procedures. The second is that optimal memory performance results from encoding highly specific semantic information about each individual item or event. Age differences in retention are attributed to age-related differences in the depth or elaborateness to which material is processed (Dick & Engle 1984).

Instruction in rehearsal strategies often mediates age-related differences in recall reported in memory research. Several researchers have found no differences in recall across ages after rehearsal strategy training. Bjorklund and Bjorklund (1985) taught organizational strategies to children in grades 1, 3, and 5. There was no evidence of higher recall for either effect at any grade. Hall and Madsen (1978) found similar results when training third and fifth graders on encoding and retrieval strategies. Although training produced greater clustering of items, it did not produce greater recall for either age group.

Other researchers demonstrated that rehearsal strategy training produced significant changes in recall for all age groups. Ornstein, Naus, and Liberty (1975) investigated effects of item blocking on recall of words with children in grades 3, 6, and 8. Although older children were more active in rehearsal, item-blocked strategy

produced higher recall for all age groups. In a similar experiment, Ornstein, Stone and Naus (1977) taught a grouping strategy to second and sixth graders. Recall was higher for both groups, with both groups choosing to employ the strategy on later tasks. Cox, Ornstein, Naus, Maxfield, and Zimler (1989) investigated the effect of multiple strategy training on recall with third and sixth graders. Multiple strategy use produced an additive effect on recall for both age groups. Keniston and Flavell (1979) investigated the use of an alphabetic strategy with students in grades 1, 3, 7, and college. Alphabetic strategy was successful for all ages in recall of items.

Teachers' Role in Facilitating Memory and Study Strategy Development

Moely, Hart, Leal, Santulli, Rao, Johnson, and Hamilton (1992) observed 69 elementary school teachers, grades K-6, to classify their efforts in strategy instruction. The researchers found that strategy instruction varied by grade and content instruction. Strategy instruction occurred most often in grades 2 and 3. Teachers in grades 4 and above more often provided students with rationales for use of strategies than did teachers of younger children. In a second study, children of low, moderate, and high achievement levels were selected from classrooms where there was a relatively high use of teacher suggested strategies. Subsequent to training in the use of a memory strategy, children's performance on a maintenance trial was evaluated. Among moderate and low achievers those students whose teachers were relatively high in strategy suggestions showed better maintenance and more deliberate use of the trained strategy. There was no significant effect for high achievers. Table 2-2 contains the classification of teachers' strategy suggestions (Moely et al., 1992).

Table 2-2

Classification of Teachers' Strategy Suggestions

Rote Learning
Rote learning strategies are instructed for simple repetitive learning. Children are told to rehearse stimuli verbally, or to write, look at, go over, study, or repeat them in some other way. The children may be instructed to rehearse items just once, a finite number of times, or an unlimited number of times. Rote learning strategies do not include any explicit activities that would add meaning to the stimulus or cause it to be processed to a deeper level or in terms of more extensive associative relations.

Elaboration
The elaboration strategy is instructed for use with stimulus materials that generally do not have much intrinsic meaning to children, such as the definition or pronunciation of words. Children are instructed to use elements of the stimulus material and assign meaning by making up a phrase or sentence, making an analogy, or drawing a relation based on specific characteristics found in the stimulus material.

Deduction
In deduction, children are instructed to use their general knowledge in combination with any clue from the material that seems helpful, to deduce and construct the correct answer. Teachers might direct children to use contextual information (e.g., pictures accompanying a text or parts of the text) or to analyze the item into smaller units (e.g., looking for root words, analyzing words phonetically).

Transformation
Transformation is a strategy suggested by teachers for transforming unfamiliar or difficult problems into familiar or simpler ones that can then be solved more easily. Transformations are possible because of logical, rule-governed relations between stimulus elements. Teachers identify these relations and tell children either that a problem can be rewritten or that it can be reformulated if the method of solution is related or derived from rules and procedures learned previously. Due to the emphasis on logical, rule-governed relations, this strategy is usually suggested in mathematics.

Specific Aids for Problem Solving and Memorizing
This strategy involves the use of specific aids in problem solving or memorizing. Even though these aids may have other uses, the teacher instructs one specific application of them. Teachers may give explicit instructions on how to use the aids in the task at hand. Thus, children are instructed to use objects, body parts, or assigned reading materials in learning and memory tasks. For example, teachers often told children to use blocks or other counters to represent addition or subtraction operations in a concrete way.

General Aids
In contrast to specific aids, teachers recommend the same general aid for a variety of different problems. These aids are designed and used to serve a general reference purpose. Children often have prior training in their use, and once familiar with them, are expected to utilize them without further explanation. Examples include the use of dictionaries or other reference works.

Table 2-2--continued.

Imagery

This strategy usually consists of nonspecific instructions to visualize items, by forming a mental picture of them or to maintain or manipulate them in the mind. It also refers to visualizing procedures or characters.

Exclusion

This is a strategy to help children answer test or workbook questions even if they don't know the correct answer initially. Children are told to eliminate incorrect options systematically either by doing the problems they know first and then trying to match questions and answers that are left over, or by trying out all possibilities and selecting the one that seems correct.

Attention

These strategies are suggested by teachers to direct or maintain children's attention to a task. For example, teachers may instruct children to "follow along" or "listen carefully" during lessons.

Specific Attentional Aids

This strategy is similar to the attention strategy, but children are instructed to use objects, language, or a part of their body in a specific way to maintain orientation to a task. Although these aids are employed in a specific way for the attentional task, they may have other uses ordinarily.

Self Checking

Teachers instructing this strategy suggest that children check their work for errors before turning it in. It includes procedures children can use on their own to make sure they are doing a task correctly. Teachers may also suggest that children test themselves or have someone else test them. Or children might be encouraged to keep track of all steps involved in a task so that they can later identify where they made a mistake. The instructions for this strategy are often not specific but rather a general remark to "check" the work.

Metamemory

Teachers instructing this strategy tell children that certain procedures will be more helpful for studying and remembering than others, and sometimes teachers may also explain why this is so. The instruction frequently includes giving hints about the limits of memory, asking children about the task factors that will influence ease of remembering, or helping them understand the reasons for their own performance. Teachers may ask children how they can focus memory efforts effectively, or what they can do to remember. Teachers also tell children that they can devise procedures that will aid their memory or indicate the value of using a specific strategy.

Moely et al. (1992) suggested that frequency of strategy instruction aids in retention and maintenance of skills. There are educational benefits for low and moderate ability children when teachers increase the frequency of strategy suggestion or instruction.

Drill, Practice, and Principles of Memorization

Drill is a teaching strategy in which repetition is used to develop precision in learning and retention of facts in memory. The consensus of researchers is that drill in learning basic facts should begin only after relevant concepts, such as number meaning, addition, and subtraction are developed.

Davis (1978) provided clear indications for when a child is ready for memorization of basic math facts. The six indications include the following:

1. The child can create or recognize embodiments of the fact using number line fingers, or manipulatives.
2. The child can understand the concepts in the fact (numbers and symbols).
3. The child can use the fact in simple exercises.
4. The child can make up a story problem using a fact.
5. The child can show the truth of the fact using objects, models, or other facts.
6. The child can compute related statements of the number fact, such as computing a missing addend.

Driscoll (1980) summarized principles for effective instruction in memorization of basic math facts. Children should begin to memorize basic arithmetic facts soon after they demonstrate an understanding of symbolic statements. They should participate in drill with the intent to memorize. Because the goal of drill is remembering, there should be no explanations during drill sessions. Drill sessions should be short and should occur

daily. Children should memorize only a few facts at a time and constantly review previously memorized facts.

Teachers have an active role in providing effective drill experiences. The teacher's roles are to express confidence in the students' ability to memorize and to praise students for good, focused effort. Another role for teachers is to keep records of student progress, including rate and errors, so that drill activities maximize performance.

Research on Effective Drill Practice

Two research findings are relevant to effective instructional practice with drill. Davis (1978) reported that over 100 teachers conducted a 2- to 6- week drill program with basic facts. They included a 5- or 10 -minute drill session daily and grouped students according to particular facts children needed to memorize. Use of short drills, combined with individualization of facts to be learned, produced positive results and high teacher satisfaction with the program.

Good and Grouws (1979) investigated the effectiveness of instructional scheduling on math achievement with fourth grade students. The experimental group of teachers followed a strict schedule of instruction that specified teacher behavior and time allotments for instruction: (a) 8 minutes for review of previous lesson, (b) 30 minutes for development of new material, and (c) 15 minutes for uninterrupted practice of basic skills. The control group did not have specified practice time. The combination of review, development, and practice produced gains of 25 percentile points on the Metropolitan Achievement Test (MAT) in 2-1/2 months.

Effective drill and practice is a necessary component in development of computational skills. Effective practice involves students' understanding of the processes

underlying the skill and teachers' awareness of essential instructional components to facilitate success.

Memory

Atkinson and Shiffrin (1968) published a theory of human memory that captured the then current thinking concerning the nature of human memory (see Figure 2-1). The model included a two-storage memory system, the short-term and long-term memory. Short-term memory was thought to be a temporary storage system that could hold a small amount of information. Information was maintained by repeating the information, thus strengthening the chance for retrieval on presentation of stimulus. Repetition, or rehearsal, was thought to be the process by which information was transferred from short term memory to long term memory.

According to Atkinson and Shiffrin (1968), information comes into short-term memory from the environment through perceptual processes. The subject engages in rehearsal of information held in short-term memory. Every time information is rehearsed, there is another chance for it to be transferred to long-term memory. Thus, increased rehearsal of information results in the probability of long-term storage. Since there is limited storage in short-term memory, each time the subject decides to take in a new item for rehearsal, an old item is displaced or forgotten.

The Atkinson Shiffrin (1968) model did not address several areas in memory research, such as the role of organization and retrieval conditions. The researchers offered no explanation to account for instances when rehearsal did little to improve long-term memory.

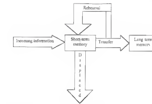

Figure 2-1 Atkinson and Shiffrin Model of Memory

Craik and Lockhart (1972) argued that what was critical was the depth to which information was processed. According to their theory, called the depth of processing theory rehearsal only improves memory if the material is rehearsed in a deep and meaningful way In other words memory only improves if the rehearsal creates a deeper encoding of material. The depth of processing theory is criticized because the concept of depth is vague and difficult to measure

Other researchers suggested that rehearsal strategies might be better termed elaborative strategies (Bekerian & Baddeley 1980 Bradshaw & Anderson 1982) Elaborative strategies require the subject to create additional ways of encoding the item to be remembered Rehearsal strategies such as sorting categorizing, and semantic encoding are examples of elaborative strategies.

Memory theorists also assumed a property of strength within the encoding process Memory is assumed to have a property called strength which increases with repeated practice Proponents of strength theories thought that strength implied conditioning in terms of synaptic connections Strength is viewed as indicating the degree to which cues can activate the memory The more the memory could be activated the more available it could be (Anderson 1981 Pirolli & Anderson 1985)

Instance theorists viewed the mechanism of memory as a consequence of attention (Hintzman 1976 Logan, 1988 Ross 1984) People store in memory everything they attend to whether or not they want to remember it In other words attention is a nonselective process that encodes a person s experiences, whether there is any intention to learn or not. Logan specifically applied instance theory to single-item direct access memory tasks in order to investigate the development of automaticity

Logan s Instance Theory of Automatization

Over the past decade, considerable progress has been made in understanding the process of memory and automaticity including the conditions under which it may be acquired Automatic processing is fast, effortless autonomous, stereotypic and unavailable to conscious awareness Automaticity is acquired only in consistent task environments as when stimuli are mapped consistently onto the same responses throughout practice Most of the properties of automaticity develop through practice in such environments

Instance theory relates automaticity to the memory component of attention Automaticity is a memory phenomenon governed by theoretical and empirical principles that govern memory Automaticity is memory retrieval

Performance is automatic when it is based on single step direct access retrieval of past solutions from memory Logan (1988) assumed that novices begin with a general algorithm that is sufficient to perform a task. As novices gain experience, they learn specific solutions to specific problems which they retrieve when they encounter the same problems again They can respond with a solution retrieved from memory or one computed by use of an algorithm At some point, individuals gain enough experience to respond with a solution from memory on every trial and abandon the algorithm entirely At that point, performance is automatic Automatization reflects a transition from algorithm-based performance to memory based performance.

Instance theory is well illustrated in children s acquisition of simple arithmetic Initially, children learn to add single-digit numbers by counting a slow and laborious process, but one that guarantees correct answers if applied correctly With experience however children memorize the sums of single digits and rely on memory retrieval rather than counting (Ashcraft 1982) Once memory becomes sufficiently reliable children rely on memory entirely

Main Assumptions of Logan s Instance Theory

Logan's (1988) instance theory has three assumptions First the process of encoding into memory is an obligatory unavoidable consequence of attention Attending to a stimulus is sufficient to commit to memory It may be remembered well or poorly but it will be encoded

Second, retrieval from memory is an obligatory unavoidable consequence of attention Attending to a stimulus is sufficient to retrieve from memory whatever has been associated with it in the past. Retrieval may not always be successful but it occurs

nevertheless. Encoding and retrieval are linked through attention. The same act of attention that causes encoding also causes retrieval

Third, each encounter with a stimulus is encoded, stored, and retrieved separately This makes the theory an *instance theory*

The three assumptions imply a learning mechanism—the accumulation of separate episodic traces with experience—that produces a gradual transition from algorithmic processing to memory-based processing The assumption of obligatory encoding is supported by studies of incidental learning and comparisons of incidental and intentional learning People can learn large quantities of information without the intent to learn. Incidental learning occurs at a higher probability than chance The intention to learn seems to have little effect beyond focusing attention on the items to be learned (Hyde & Jenkins, 1969) However the first assumption of obligatory encoding does not imply that all items will be encoded equally well Attention to an item may be sufficient to encode it into memory, but the quality of the encoding will depend on the quality and quantity of attention

The second assumption of obligatory retrieval is supported by studies of Stroop and priming effects. With Stroop and priming effects attention to an item activates associations in memory that either facilitates performance in some situations or interferes with performance in others The assumption of obligatory retrieval does not imply that retrieval will always be successful or that it will be easy Many factors affect retrieval time, including practice on the task (Pirolli & Anderson, 1985)

The third assumption of an instance theory differentiates instance theory from strength and process-based theories of memory Many theorists assume a strength

representation and others include strength as one of several learning mechanisms (Anderson 1981 Pirolli & Anderson 1985) In strength theories, memory becomes stronger by strengthening a connection between a generic representation of a stimulus and a generic representation of its interpretation or its response In instance theory memory becomes stronger because each experience lays down a separate trace that may be recruited at the time of retrieval

In instance theory automatization is item based rather than process based Automatization involves learning specific responses to specific stimuli The underlying processes need not change at all Subjects are still capable of using the algorithm at any point in practice, and memory retrieval may operate in the same way regardless of the amount of information to be retrieved. Automaticity is specific to the stimuli and the situation experienced during training According to instance theorists transfer of knowledge to novel stimuli and novel situations should be poor

The instance theory differs from process based views of automatization. Process-based models view automatization as process-based, making the underlying process more efficient, reducing the amount of resources required or reducing the number of steps to be executed Process-based learning should transfer just as well to novel situations with novel stimuli as it does to familiar situations with familiar stimuli Instance theory differs from process-based views of automatization in that there is an assumption that a task is performed differently when it is automatic than when it is not Automatic performance is based on memory retrieval Nonautomatic performance is based on an algorithm

Quantitative Properties of Instance Theory

Logan's (1988) theory accounts for the major quantitative properties of automatization, the speed-up in processing, and reduction in variability that result from practice. The speed up follows a regular function, characterized by substantial gains early in practice that diminish with further experience. It is observed in nearly every task that is subject to practice effects (Newell & Rosenbloom, 1981). More formally, the speed-up follows a power function,

$$RT = a + bN^{(-c)}$$

where **RT** is the time required to do the task, **N** is the number of practice trials, and *a*, *b*, and *c* are constants. The *a* represents the asymptote, *b* is the difference between initial performance and asymptotic performance, which is the amount to be learned, and *c* is the rate of learning.

In instance theory, each encounter with a stimulus is encoded, stored, and retrieved separately. Each encounter with a stimulus is represented as a processing episode, which consists of (a) the goal the subject was trying to attain, (b) the stimulus encountered in pursuit of the goal, (c) the interpretation given to the stimulus with respect to the goal, and (d) the response made to the stimulus. When the stimulus is encountered again, the subject has two choices: (a) to respond on the basis of retrieved information, if it is coherent and consistent with the goals of the current task or (b) to run off the relevant algorithm and compute a response.

The simplest way to model the choice process is to conceptualize a race between a memory retrieval of a fact and a problem-solving algorithm. Whichever finishes first controls the response. Over practice, memory comes to dominate an algorithm because

more and more instances enter the race The more instances (opportunities) there are the more likely it is that at least one of them will win the race According to instance theorists automatization reflects a transition from performance *based on an algorithm* to performance *based on memory retrieval* In effect, an algorithm races against the fastest instance retrieved from memory Eventually an algorithm will lose because its finishing time (distribution) stays the same while the finishing time for the retrieval process decreases. At some point, performance will depend on memory entirely

Assessing Learning Rate with Instance Theory

Learning rate can be assessed in two ways (a) in terms of sessions of practice or (b) trial per item Typically, learning is assessed as a function of sessions of practice, disregarding how often the items appeared in each session According to Logan and Klapp (1991), this assessment is inappropriate The crucial variable is the number of trials per item which reflect the opportunity to have memorized the items When the conditions being compared involve the same number of items, the two methods of assessing learning rate are equivalent However when different numbers of items are learned, trial per item is the more appropriate analysis

Instance Theory and Mental Arithmetic

Children s acquisition of mental addition skills is a paradigm of automaticity Typically children learn to add with a general counting algorithm based on knowledge of the sequence of numbers (Groen & Parkman 1972) With experience they streamline the algorithm, beginning their count with the larger addend and counting once for each unit of the small addend (the min strategy see Groen & Parkman) The counting

algorithm is a general one that allows children to add any two numbers. With further experience children memorize the sums of single digits and retrieve the sums directly from memory instead of counting (Ashcraft, 1982; Siegler, 1987). By the time they reach adulthood, addition has many of the properties of automaticity. It is fast, effortless, and obligatory.

Logan and Klapp (1991) discussed problems that occur when using children and the task of addition to study the development of automaticity. First, the transition from counting to remembering occurs in young children—in some cases, as early as the second grade, whose reaction time performance is notoriously slow and variable. Second, the transition from algorithm-based performance to memory based performance is most apparent when comparing children at different age levels. The comparison is confounded with large changes in base reaction time. For example, a first grader may take twice as long to perform a task as a fifth grader (Kail, 1986, 1988). Third, the amount of practice with addition is largely unknown and difficult to control for practical and ethical reasons. It may vary substantially in the same grade, in the same classroom, and among members of a math group.

Instance Theory and Practice

An assumption of instance theory is that traces must be available in memory to produce automaticity. Extended practice may be sufficient to produce automaticity insofar as it guarantees that traces will be available but is not theoretically necessary. A sufficient number of traces could be made available by other methods (e.g., deliberate memorization) in a relatively short period of time. Having traces available in memory is crucial to retrieval. The method of attention is less important. Extended practice may

strengthen automaticity by adding even more traces to memory, and performance may continue to improve indefinitely, but in theory, extended practice is not necessary to produce automaticity.

Research on Instance Theory

Logan and Klapp (1991) investigated the necessity of extended practice in producing automaticity. They reported four experiments relating to automatizing performance on a novel task called alphabet-arithmetic. The first experiment was a conventional automaticity experiment, demonstrating that extended practice was sufficient to produce important characteristics of automaticity. In the second experiment they tested the necessity of extended practice. In experiment three, they examined the effects of the number of items to be learned. Experiment four was an investigation of method of learning.

To circumvent the problems in using addition to study development of automaticity mentioned above, the researchers developed an alphabet arithmetic task in which adults learned to add digits to letters of the alphabet to produce other letters of the alphabet. As in numerical addition, this task was initially performed by a counting algorithm in which subjects counted through the alphabet from the initial letter for a number of steps determined by the digit addend to recover the true sum of the letter and digit (e.g., A + 2 = C), which they compared with the presented sum and reported an incorrect or correct match. Analogous to counting with numbers, the counting algorithm requires knowledge of the alphabet sequence and the ability to count through the sequence. The researchers tested adult participants whose (a) reaction times were fast and relatively invariant (compared to children), (b) base reaction times were not likely to

change much over the course of the experiments, and (a) experience with the task was tightly controlled The researchers interviewed participants on their impressions of transitioning from counting to remembering performances

According to automaticity-memory theorists, memory-based performance should be faster than algorithm based performance because subjects should not switch to memory until memory is faster and more reliable than an algorithm The process of automaticity should be evident as a reduction in reaction time and an increase in speed over practice

In experiment one data were characteristic of automatization in that automaticity took a long time to develop Several aspects of the data provided evidence of the development of automaticity in the alphabet-arithmetic task. First, reaction time decreased Second, participants reported a transition from algorithm to memory performance Third, transfer to new items was poor

In experiment two the researchers investigated whether extended practice was necessary to develop automaticity Participants were trained on the same task but the experimenters postponed the verification task until after the facts were memorized The training was limited to one session. Results contrasted with results from experiment one In less than an hour participants attained a level of automaticity that took experiment one participants 12 sessions (5,670 trials) to attain. The experiments differed in two respects (a) the number of facts to be learned and (b) how the facts were learned

In experiment three the investigators (a) determined whether rate of automatization depended on the amount to be learned and (b) assessed the effect of similarity on transfer to facts not experienced in training. Participants trained on 6 12

and 18 alphabet-arithmetic facts using the verification task. Participants trained on 6 and 12 facts were then transferred to a set of 18 facts. Six were old facts (old digit-old letters), six were new facts about old letters (new digits-old letters), and six were new facts about new letters (new facts-new letters). Patterns of reaction time data were consistent with automaticity as memory theory. The different rates of automatization observed in experiments one and two were due to the different number of items to be learned.

In experiment four, *learning by rote memory* and *learning by performing the task* were compared directly. Participants were shown alphabet-arithmetic equations followed by a truth statement (the word *true* or *false* written under the position the equation occupied on a computer screen) after the subject responded. Half of the participants were told to verify the equations, pressing different keys to indicate whether the equation was true or false. The truth statement provided feedback about the correctness of response. The other half of the participants were told to memorize the equations, learning which ones were true or false. They examined the equations and pressed the space bar to reveal the truth statement. Number of exposures and nature of exposures were the same for both groups of participants. Participants were transferred to a verification task to assess what they had learned and to compare learning methods.

In experiment four, the researchers manipulated number of facts to be learned. Half of the subjects learned 6 facts and half learned 18 facts. Instance theorists predict more learning with 6 facts than with 18 facts because there are more trials per item with 6 facts. There should be no interaction between number of facts to be learned and learning

method Memory should depend on the number of presentations regardless of how those presentations were made

Learning by rote memory participants differed from *learning by performing the task* participants in several ways (a) Their reaction times were generally faster (b) they were less affected by the truth of the equation, and (c) they were less affected by the magnitude of the digit addend Number of facts had a strong effect on the amount of learning manifested in a single session Learning method had very little effect on performance. Overall, reaction times were slightly longer for *learning by rote memory* participants than for *learning by performing the task* participants but the pattern was the same In both learning methods, 18-fact groups were slower than 6-fact groups The researchers interpreted the similar effects of learning method as suggesting that method of instruction was not very important but number of presentations was crucial

Single Subject Design

Several authors have presented rationales for the use of single subject, or single case research designs for academic interventions Carlson (1985) proposed that single subject designs constitute a significant breakthrough that promises advantages for teachers, parents, diagnosticians, school psychologists, professionals in case work within penitentiaries, and special educators He listed the advantages of single subject designs

(a) Any academic behavior can be measured

(b) The effectiveness of alternative strategies is tested fairly Single subject designs are amenable to verification and refutation

(c) Teachers can design single subject investigations with minimal training

(d) Single subject designs provide clear records and conform to the rigorous controls established by researchers

(e) Single subject designs are compatible with current concerns over educational accountability and afford educators a research methodology that demonstrates the effectiveness of instructional interventions

Carlson (1985) described the appropriateness of using single subject designs with children with learning disabilities Children with learning disabilities constitute a heterogeneous population and have unique problems, characteristics and combinations of influencing conditions. Single subject designs are rigorous designs that can show the effectiveness of any type of instructional intervention for any student Results can aid in selection of relevant skills for instruction determine appropriate levels of performance and help decide when to begin and end instruction

Schloss Sedlak, Elliott, and Smothers (1982) suggested that single case experimental methodology could generate relevant research outcomes to ongoing problems in special education classrooms There are elements of single case experimental methodology that align with the diagnostic-prescriptive orientation of special education Single case design relies on the practitioner s assessment of the learning characteristics of children with disabilities and facilitates the matching of innovative educational practices with identified learning characteristics It is a systematic approach and is flexible to allow for modification of educational strategies as indicated by a student s performance Single case design does not rely on the comparison of separate individuals but on the progress of one individual under different program conditions Analyses of results allow practitioners to validly and reliably assess the effectiveness of a given educational practice for an individual The authors concluded that single case methodology could establish valid causal statements regarding the association between educational treatments and behavior change

McCormick (1990) stated that the evolution of single subject methodology was a response to results of numerous experiments with treatments that had unquestionably been helpful to individual patients but were not statistically significant in group studies "The fault was believed to lie with the averaging of data across subjects in an attempt to get a representative patient, when in reality it was the individual variability in the patient that was important in much of the treatment procedure" (p 72)

McCormick (1990) stated that studies employing single case experimental methodology are appearing in an increasing number of major journals in fields such as psychiatry psychology special education, physical education and therapeutic recreation She reported that more than 20 journals have as their primary focus the publishing of single subject research. Furthermore she noted that grants awarded by the United States Office of Special Education for research frequently employ single case methodology

According to McCormick (1990), single case research methodology has attained respectability and does offer possibilities for research She listed four reasons to consider the use of single case designs. First, single case designs are particularly suited for remedial and clinical populations When results are based on mean responses, the heterogeneity of students aptitudes, learning characteristics and needs is often obscured since students in special populations frequently do not conform to the mean Single case designs allow for an individualized evaluation strategy A second use involves settings where collection of data with large populations is impractical Single case designs use each individual as his own control A third use is in combination with naturalistic or qualitative research Collecting data and recording student information can be combined

with single case designs. Fourth, single case research procedures are reasonably easy to implement. They can facilitate action research by practitioners in the schools.

Single subject research methodology is applicable to academic skills and appropriate for special populations. The sophisticated designs control for internal validity and are amenable to replication and refutation. Single subject design is a method of research particularly suited for the diagnostic-prescriptive orientation of special education and is a viable research tool for action research in the school environment.

Summary

Research related to retrieval of basic subtraction facts involves an analysis and synthesis of research findings from the areas of memory rehearsal strategies, fluency-based instruction, and mathematics instruction. Memory researchers provided the theoretical framework. Researchers in the fields of math instruction, fluency-based instruction, and rehearsal strategies provided relevant findings for understanding both the processes involved in children's mental arithmetic and best practices for mathematics instruction.

According to Logan's (1988) instance theory of automatization, there are three assumptions related to learning. The first two are that encoding and retrieving are unavoidable consequences of attention to a stimulus. The third assumption is that each encounter with a stimulus is encoded, stored, and retrieved separately. The third assumption gives instance theory its name.

The three assumptions of instance theory imply a learning mechanism. Learning is an accumulation of separate episodic traces gained through experience. The

accumulation of traces produces a transition from algorithmic processing to memory based processing.

Automatic or fluent behavior is the result of a transition to memory based processing. The novice learner begins a learning task with a general algorithm to perform a task. As the novice learner gains experience (instances) he learns specific solutions to specific tasks, which he retrieves when he encounters the same task again. At some point, enough instances are accumulated to respond with a solution from memory. The algorithm is abandoned and behavior is automatic.

Instance theory is applicable to single-step, direct access retrieval of basic mathematics facts. Children initially learn to add or subtract single digit numbers by counting. The counting strategies employed by children take numerous forms. With experience, children begin to learn the sums or differences of single digit addition or subtraction facts by rote. They begin to rely on memory retrieval rather than rely on a counting algorithm.

Research findings in memory-rehearsal strategies extend knowledge of automatic behavior. Numerous researchers demonstrated that rehearsal strategies, such as semantic encoding, categorizing, sorting, verbal rehearsal, and cumulative rehearsal increased recall of items with children of all ages (Keniston & Flavell, 1979; Ornstein, Naus, & Liberty, 1975). Children as young as prekindergarten can be taught to use rehearsal strategies that increase performance. Researchers found that instructing children on the value of rehearsal strategies, as well as providing feedback, significantly improved performance (Kennedy & Miller, 1976; Lacher, 1983).

There are serious gaps in the memory and rehearsal strategy research as it pertains to children and increased academic performance. First, over 90% of relevant studies in memory strategy research focused on the assessment of age-correlated differences (Schneider & Sodian 1997). Comparison of aggregated average strategy scores across age groups continues to support the position that strategy development is a regular continuous sequence of changes in cognitive competence and related memory skills. There is a scarcity of research examining the effects of rehearsal strategies within age groups.

Second, the majority of rehearsal strategy researchers have been concerned with the effects of strategies on recall of serial or unrelated items. Few studies have investigated effects of rehearsal strategies on single item retrieval tasks such as basic arithmetic facts. Third, memory research and strategy research agendas have not been extended to educationally relevant tasks in natural settings. Further investigations are needed to expand knowledge of memory development in children as it relates to educational tasks in educational settings.

Research findings from fluency-based instruction provided empirical support for inclusion of rehearsal strategies, specifically drill and practice within a curriculum. Researchers in fluency training reported substantial academic gains for students when instruction was redirected to include extensive drill and practice on basic tool skills and computational skills (Binder 1996 Johnson & Layng, 1994).

Although researchers have suggested proficiency rates for basic arithmetic facts rates vary considerably across studies. Suggested rates for proficiency of subtraction facts from 18 ranged from 40-60 digits per minute (Starlin & Starlin, 1973) to 70 90

digits per minute recommended by the Precision Teaching Project data in the 1970s. All suggested rates were for written math facts. Howell and Morehead (1987) were the only researchers to suggest written and oral proficiency rates. The effectiveness of oral practice on fluency building has not been empirically validated.

Researchers of mathematics instruction provided additional support and guidelines for inclusion of drill and practice as an effective rehearsal strategy within a mathematics curriculum. Researchers offered principles and effective teaching strategies for drill and practice (Davis, 1978; Driscoll, 1990).

Effective drill and practice require both a readiness level on the part of the learner and particular teacher behaviors. Children must be able to demonstrate knowledge of the underlying concepts of number properties, addition, and subtraction before initiation of drill. Planning and implementing effective practice require specific teacher behaviors and an adherence to scheduling. Researchers reported positive academic gains from drill when instructors informed learners of the value of the strategy (Moely et al., 1992). Intensive, daily drill for short periods of time produced significant effects (Davis, 1978; Good and Grouws, 1979).

Knowledge of how and when children learn, as well as effective instructional practices to increase performance, can be synthesized from research findings in the areas of memory rehearsal strategies, fluency-based instruction, and mathematics instruction. The memory-rehearsal literature contains numerous studies of the effectiveness of rehearsal strategies to improve children's academic performance.

The fluency-based instruction literature contains numerous studies of the effectiveness of fluency training to improve children's performance. Fluency of

prerequisite skills is a necessary component for the successful acquisition of higher level skills in mathematics. Researchers in mathematics instruction have provided guidelines for implementing practice that is meaningful to students.

In mathematics instruction, children develop two components of knowledge about arithmetic. Procedural knowledge allows the learner to use algorithms to solve computational problems. Declarative knowledge of facts allows the learner to retrieve answers from memory and reduces the amount of response time to solve computational problems.

Interventions that employ rehearsal strategies to increase the amount of declarative knowledge in order to accelerate performance are potentially valid instructional procedures. The present study investigated the effects of two rehearsal strategies on retrieval of basic subtraction facts. Logan's (1988) instance theory of automatization provides a theoretical framework in which to examine the effectiveness of rehearsal strategies that increase performance. Instance theorists predict that there will be no difference in effectiveness of oral and written practice on retrieval of basic subtraction facts if the methodology includes an equal number of presentations of each item.

The purposes of this study were to test the validity of an instance theory of automaticity using two forms of rehearsal and to evaluate their efficacy on memory retrieval. Logan's (1988) theory of automaticity has been validated with adults in a laboratory setting using a pseudo memory task. The investigator used an ABAB single subject design to test the validity of instance theory as it relates to method of learning in the following ways: (a) specific rehearsal strategies will be applied to an educationally relevant task, (b) rehearsal strategy instruction will take place in a natural, school

environment, and (c) participant selection will include middle school children who exhibit a learning disability in mathematics. The study compares the effectiveness of oral and written rehearsal on retrieval of basic subtraction facts

CHAPTER 3
MATERIALS AND METHODS

The rehearsal strategies described in Chapter 3 were designed to enhance performance on basic subtraction facts by middle school students who exhibited a learning disability in mathematics and to determine which strategy was more effective for each student. Performance on subtraction facts was used to (a) empirically test an instance theory of automaticity (Logan, 1988) and (b) evaluate the effectiveness of two rehearsal strategies. Chapter three includes the following sections: (a) participants and setting, (b) materials, (c) response and interobserver agreement, (d) experimental design, (e) procedures, (f) social validity, and (g) results.

Participants and Setting

Six middle school students (grades 6 through 8) participated in the study. Five students were 12 years old and one student was 13. The study was conducted in middle school special education classrooms for students in grades 6 through 8. Instruction took place during the regularly scheduled mathematics class. To participate in the study, each participant was required to meet all of the following criteria:

1. The participant met the state of Florida (Department of Education) definition for eligibility for educational services for students with learning disabilities.
2. The participant was identified as having a learning disability in mathematics.
3. The participant was receiving special education services for part of the school day for instruction in mathematics.

4. The participant was not eligible for other special educational programs or support services
5. The participant had normal intelligence (within one standard deviation above or below the mean) as measured by a standardized individually administered measure of general ability
6. The participant was identified by teachers as deficient in speed, accuracy or recall of basic subtraction facts.
7. The participant did not have a history of absenteeism or frequent moves
8. The participant had not been retained in the same grade more than once in his/her school experience.
9. The participant's parents or guardians signed a parent consent form
10. The participant signed the child assent form

Smith, Deshler Hallahan, Robinson, Voress, and Ysseldyke (1984) recommended guidelines for describing participants with learning disabilities in published reports In the current study descriptive data for each student included gender age, grade ethnicity socioeconomic status (SES) special education status (exceptionality) individually administered general ability score, and a measure of achievement in mathematics within the last 2 years These data were consistent with those deemed relevant by Smith et al

For participants, a score on a measure of general ability was obtained from psychological reports required for inclusion in special education programs Mathematics achievement scores were obtained from the most recent administered educational assessment. Socioeconomic status was indicated by eligibility for the assisted lunch program available to students

Participant One

Participant One was a 12-year old, black female in the seventh grade who received the assisted lunch program. She was enrolled in special education classes for math instruction based on a Wechsler Individual Achievement Test (WIAT) score of seventh percentile in numerical operations. Her general measure of ability score (92) was assessed with the Kauffman Assessment Battery for Children.

During screening procedures the participant used a variety of strategies for solving subtraction facts. When the response to the fact was oral the participant used fingers on both hands to count up. When a written response was required, the participant used one hand and double counted on fingers to solve the fact problem. The participant's tool skill of saying numbers was 1.3 times faster than her written tool skill. The screening identified 11 nonautomatic responses to *facts from 9* and 35 nonautomatic responses to *facts from 18*.

Participant Two

Participant Two was a 12-year-old, black male in the seventh grade who received the assisted lunch program. He was enrolled in special education classes for math instruction based on a standard score of 56 in mathematics on the Woodcock-Johnson Tests of Achievement. His general measure of ability score (95) was assessed with the Kauffman Assessment Battery for Children.

During screening procedures, the participant used a counting up from strategy with fingers for solving subtraction facts. The participant was left handed and positioned his wrist above the problem to write. The participant's tool skill of saying numbers was

1 3 times faster than his written tool skill The screening identified eight nonautomatic responses to *facts from* 9 and 34 nonautomatic responses to *facts from 18*

Participant Three

Participant Three was a 12-year-old white male in the sixth grade He was enrolled in special education classes for math instruction based on an FCAT score of 42nd percentile in mathematics His general measure of ability (102) was assessed with the Wechsler Intelligence Scale for Children III (WISC-III)

During screening procedures, the participant used mental counting for solving subtraction facts He counted up or down depending on which strategy was faster The participant s tool skill of saying numbers was 1 3 times faster than his written tool rate. The screening identified 10 nonautomatic responses to *facts from 9* and 32 nonautomatic responses to *facts from 18*

Participant Four

Participant Four was a 12-year-old, black male in the seventh grade who received the assisted lunch program He was retained in kindergarten He was enrolled in special education classes for math instruction based on a standard score of 85 in mathematics on the Wechsler Individual Achievement Test (WIAT) His general measure of ability (102) was assessed with the Kauffman Assessment Battery for Children

During screening procedures the participant used a counting up from strategy with fingers to solve subtraction facts The participant s tool skill of saying numbers was 4 2 times faster than his written tool rate The screening identified 9 nonautomatic responses to *facts from 9* and 34 nonautomatic responses to *facts from 18*

Participant Five

Participant Five was a 12-year-old, white female in the sixth grade. She was enrolled in special education classes for math instruction based on a standard score of 77 in mathematics on the Woodcock-Johnson Tests of Achievement. Her general measure of ability (100) was assessed with the Kauffman Assessment Battery for Children.

During screening procedures the participant used a counting up from strategy with fingers for solving subtraction facts. The participant's tool skill of saying numbers was 2.4 times faster than her written tool skill. The screening identified 23 nonautomatic responses to *facts from 9* and 39 nonautomatic responses to *facts from 18*.

Participant Six

Participant Six was a 13-year-old, white female in the eighth grade. She was retained in kindergarten. She was enrolled in special education classes for math instruction based on a standard score of 71 in mathematics on the Woodcock-Johnson Tests of Achievement. Her general measure of ability (100) was assessed with the Kauffman Assessment Battery for Children.

During screening procedures, the participant used a variety of strategies for solving subtraction facts. When the fact contained numbers less than ten, the participant used her fingers to count out the minuend, count off the subtrahend, and count the remaining fingers for the answer. When the fact contained numbers greater than 10, the participant counted up using her fingers. She visually recognized the number of fingers for the answer. The participant's tool skill of saying numbers was 1.4 times faster than her written tool skill. The screening identified 12 nonautomatic responses to *facts from 9* and 36 nonautomatic responses to *facts from 18*.

Table 3-1 displays the demographic data on the participants. The participants met all criteria for inclusion in the study.

Table 3-1

Demographic Data on Participants

Number	Special Education	Age	Grade	Race	Gender	Assisted Lunch Program	Ability Measure	Math Scores	Written Digits Minute	Oral Digits Minute
1	SLD	12	7	B	F	YES	92 K-ABC	7th/de WIAT	96	128
2	SLD	12	7	B	M	YES	95 K-ABC	SS 56 W-J	55	120
3	SLD	12	6	W	M	NO	102 WISC III	42%ile FCAT	86	116
4	SLD	12	7 R	B	M	YES	102 K-ABC	SS 85 WIAT	45	108
5	SLD	12	6	W	F	NO	100 K-ABC	SS 77 W-J	54	130
6	SLD	13	8 R	W	F	NO	100 K-ABC	SS 71 W-J	90	120

WISC III—Wechsler Intelligence Scale for Children III
R—Retained
SLD—Specific Learning Disability
K-ABC—Kauffman Assessment Battery for Children
W-J—Woodcock-Johnson Tests of Achievement
FCAT—Florida Comprehensive Achievement Test
WIAT—Wechsler Individual Achievement Test
SS—Standard Score

Materials

Screenings of basic subtraction facts (*facts from 9 and facts from 18*) were used to develop four groups of 10 facts per participant for each phase of an experimental condition. Subtraction facts with 0 and 1, as well as subtraction facts that include doubles ($12 - 6 = 6$) were excluded from the screening. The *facts from 9* screening consisted of 33 problems and the *facts from 18* screening consisted of 39 problems. Once 40 facts had been identified for each participant and randomly distributed across four phases of an experimental condition, each participant was pretested. Participants

were pretested using oral and written assessments on two groups of facts: (a) 20 facts assigned to oral rehearsal phases and (b) 20 facts assigned to written rehearsal phases.

Response and Interobserver Agreement

Each student focused on a group of ten subtraction facts for each of four phases of an experimental condition. For each phase the 10 facts were displayed on an individual 8-1/2 by 11 task sheet. The facts were printed in 26-point type. The task sheet had five rows of subtraction facts. Each row had the same 10 facts printed in random order. Each row represented one rehearsal session. There were five rehearsal sessions per day.

During all experimental phases, timed response rate and accuracy data were collected. Data were recorded on an individual data chart (see Appendix B). The data consisted of numbers of correct and incorrect responses along with the timed response rate in seconds for each rehearsal session. At the conclusion of each phase of an experimental condition, probes of timed response rate and accuracy were administered using oral and written assessments. The order of the probes was counterbalanced across phases. Oral and written posttests were administered at the conclusion of the four phases and maintenance tests were administered 2 weeks after the conclusion of the four phases. The posttests and the maintenance tests consisted of the 20 facts assigned to oral rehearsal and the 20 facts assigned to written rehearsal. The data chart included a section for anecdotal comments.

Interobserver agreement for the dependent and independent variables was calculated in 20% of the rehearsal sessions per participant in each of the four treatment phases and in 25% of the pre-, post-, and maintenance tests. Interobserver agreement for the dependent variables (accuracy and timed response rate) was calculated by frequency

ratio (the smaller total divided by the larger total x 100). A difference of less than 2 seconds between observers for timed rate of response was considered an agreement.

Interobserver agreement for the independent variable (method of rehearsal) was calculated using a point-by-point agreement ratio for adherence to steps in the scripted directions for treatment sessions (see Appendix B). A point-by-point agreement was calculated by dividing the number of agreements by the number of agreements plus disagreements and multiplying by 100.

Experimental Design

An ABAB comparison of treatment design was used to test an instance theory of automaticity and to compare the effectiveness of oral and written rehearsal strategies using basic subtraction facts. An ABAB design consists of making and testing predictions about performance under different conditions. By altering experimental conditions in the design, there are several different opportunities to compare phases and compare treatments. According to Kazdin (1982) ABAB designs represent methodologically powerful experimental tools for demonstrating intervention effects. When the pattern of the data reveals shifts in performance as a function of alteration of the phases, the evidence of intervention effects is demonstrated.

Six students were randomly assigned to one of two experimental conditions: (a) oral-written-oral-written or (b) written-oral-written-oral. Each phase of an experimental condition included five sessions per day for a total of 25 rehearsal sessions. Three participants were randomly assigned to the oral-written-oral-written condition of the study and three participants were randomly assigned to the written-oral-written-oral

condition of the study Figure 3-1 describes the two conditions Letter A denotes written rehearsal and letter B denotes oral rehearsal

Condition 1

A1	B1	A2	B2
(written)	(oral)	(written)	(oral)

Condition 2

B1	A1	B2	A2
(oral)	(written)	(oral)	(written)

Figure 3-1 Conditions of the Experiment

Facts from 9 and *facts from 18* screenings determined the absence of automaticity on each group of subtraction facts to be rehearsed. The study began with pretests for each participant. Participants were pretested using oral and written formats for 20 facts assigned to oral rehearsal phases Participants were then pretested using oral and written formats for 20 facts assigned to written rehearsal phases Further baseline data were not collected in order to eliminate the effects of practice on targeted facts The first timed rehearsal of each phase was a measurement of initial performance by the participant At the end of each phase (session 25) the experimenter administered oral and written probes. For example if 10 facts were rehearsed orally oral and written probes of the 10 facts occurred after the 25th oral session

Method of rehearsal was the independent variable in the investigation Rehearsal occurred in two ways (a) rehearsal was oral and (b) rehearsal was written Both

rehearsal strategies were intended to improve the recall of basic subtraction facts According to Logan s (1988) instance theory of automatization if the number of instances to learn is equal the learning method will have little effect on performance

The dependent variables across all four phases were response rate and accuracy Measurement of the dependent variables was assessed using numbers correct and incorrect as well as timed response rate in seconds for each group of 10 facts for each participant Oral and written probes of timed response rate and accuracy were administered after the 25th session for each phase of an experimental condition Oral and written posttests of the 20 facts assigned to oral rehearsal and of the 20 facts assigned to written rehearsal were administered at the conclusion of the four phases of the study and maintenance tests were administered 2 weeks after the conclusion of the final experimental phase

Procedures

All participants were screened with an experimenter-designed procedure to assess applications of strategies for solving a subtraction problem The screening procedure was accomplished in an experimenter child work session prior to initiation of treatment. The work session lasted approximately 15 minutes, or until the participant completed all components of the screening procedure

In the first component the participant demonstrated strategies for solving a subtraction problem by performing the following activities using a fact (10 5 = ?) supplied by the experimenter The participant performed all activities with 100% accuracy in order to be included in the study

1. The participant demonstrated a solution to a subtraction fact problem using manipulatives or fingers

2. The participant drew a representation of a solution to a subtraction fact problem (10 – 5 – ?) using paper and a drawing utensil

3. The participant orally produced a simple story problem using a subtraction fact (A lady has 10 apples and she eats five. How many does she have left?)

4. The participant applied a strategy for subtraction within a multi-step problem (10 - 5 – 1 – ?)

In the second component, screenings of basic subtraction facts (*facts from 9* and *facts from 18*) were used to develop four groups of 10 facts per participant for each phase of an experimental condition. Subtraction facts with 0 and 1, as well as subtraction facts that include doubles (12 - 6 = 6), were excluded from the screening. The *facts from 9* screening had 33 problems and the *facts from 18* screening had 39 problems.

Participants were screened orally for automaticity in recall of basic subtraction facts. Automaticity was defined as a response without hesitation. Participants had at least 40 nonautomatic responses for inclusion in the study. Forty nonautomatic subtraction facts were randomly distributed across the four phases, approximating the percentage missed per screening for each participant. Participants were pretested using oral and written formats for 20 facts assigned to oral rehearsal phases. Participants were then pretested using oral and written formats for 20 facts assigned to written rehearsal phases.

In the third component, participants were assessed on two tool skills: (a) saying numbers and (b) writing numbers. In a 1-minute probe, participants wrote numerals 0 through 9 as quickly as they could on a lined task sheet. In another 1-minute probe, participants read randomly printed numerals 0 through 9 as quickly as they could

Students with either written or oral tool skills of less than 30 digits per minute were excluded from the study.

Ten facts for each phase per participant were presented on an 8-1/2 by 11 task sheet. The problems were printed in 26 point type. There were five rows of facts per task sheet. Each row of a task sheet contained in random order the same 10 subtraction facts.

The experimenter was seated next to the student. Directions were given at the beginning of each day of rehearsal. On a given signal ("begin now") the student called out or wrote the answers to the row of facts. Each row was timed separately. Each day the student began rehearsal on a different row. All five rows were completed in a single day. For written rehearsal of facts the student wrote answers to problems on the task sheet. For oral rehearsal of facts, the experimenter had a duplicate task sheet for scoring responses. Corrective feedback was given to the participant at the end of each session (see Appendix B for scripted directions).

Social Validity

At the conclusion of each phase of the study as well as at the conclusion of the study, participants were asked what they liked or disliked about the rehearsal format. The investigator recorded the students' responses and solicited reasons for the response. At the conclusion of the study, participants were asked if they had a preference for either rehearsal strategy. Each student's preference was compared to his performance to determine if there was a relationship (see Appendix B for social validity questions).

Results

For each session, accuracy of responses to targeted facts was assessed. Accuracy was reported in terms of numbers of correct and incorrect responses. Corrective feedback was given to each participant at the end of each session.

For each session, timed response rate was assessed. A stopwatch was used to time the rate of response for each group of ten facts for each participant. The experimenter gave a signal ("begin now") to commence timing. Timed response rate was measured to the nearest second.

To compare the effects of oral and written rehearsal strategies on performance participants' timed response rate and accuracy were assessed in the following ways: (a) timed response rate and accuracy for each rehearsal session, (b) timed response rate and accuracy for oral and written probes at the end of each phase of the study, and (c) timed response rate and accuracy using pre-, post-, and maintenance tests.

CHAPTER 4
RESULTS AND DISCUSSION

The results of the investigation concerning the effects of two rehearsal strategies on retrieval of basic subtraction facts by middle school students with math disabilities are presented for two purposes: (a) to test the validity of an instance theory of automatization on a meaningful educational task and (b) to investigate the efficacy of oral and written rehearsal strategies related to retrieval of basic subtraction facts by middle school students with math disabilities in a school environment.

A single subject comparison of treatment design was used. The dependent variables across all phases of the study were timed response rate and accuracy. Data pertaining to participants' performance on the dependent variables have been evaluated. The research questions posed in Chapter 1 have been addressed for each participant.

The six participants, as described in Chapter 3, are referred to by their participant number throughout Chapter 4. In this chapter, data are displayed graphically and tables are used to present data. The data for participants are presented on line graphs in Figures 4-1 through 4-12. Summaries of data are presented in Tables 4-1 through 4-3. Results of interobserver agreement are included. In addition, each participant's preference for rehearsal strategy is compared to performance.

One minute probes of writing numbers and of saying numbers provided initial tool skills data that were used to calculate expected oral and written response rates for each participant during the four phases of the study. In order to generate individual pools

of 40 nonautomatic facts, participants' correct, automatic responses, or correct responses without hesitation, were eliminated using screenings of *facts from 9* and *facts from 18*.

Four effects of rehearsal strategy on fluency were evaluated in this study. The effect of oral rehearsal on oral fluency was determined by (a) calculating percentage change from initial oral mean to final oral mean in each oral phase and (b) comparing final oral mean to oral probe rate in each oral phase. The effect of oral rehearsal on written fluency was determined by comparing an expected written probe rate calculated from initial tool skills data to written probe rate in each oral phase.

The effect of written rehearsal on written fluency was determined by (a) calculating percentage change from initial written mean to final written mean in each written phase and (b) comparing final written mean to written probe rate in each written phase. The effect of written rehearsal on oral fluency was determined by comparing an expected oral probe rate calculated from initial tool skills data to oral probe rate in each written phase.

Accuracy rates are presented in Table 4-3 for each participant. The numbers of errors in both oral phases were combined to determine an overall accuracy rate for oral rehearsal. The numbers of errors in both written phases were combined to determine an overall accuracy rate for written rehearsal. In maintenance testing, a similar procedure was used. The numbers of errors in oral and written testing formats were combined to give an overall accuracy rate for the 20 facts assigned to oral rehearsal. The same procedure was followed for numbers of errors in oral and written testing formats for the 20 facts assigned to written rehearsal. Accuracy was evaluated by (a) comparing percentage of errors in oral phases to percentage of errors in written phases and (b)

comparing percentages of errors for 20 facts assigned to oral rehearsal to 20 facts assigned to written rehearsal in maintenance testing

Data pertaining to the efficacy of oral and written rehearsal strategies have been presented to evaluate effectiveness of treatments on retrieval of basic subtraction facts Short-term effects were evaluated for each phase by (a) comparing percentage change from initial mean performance to final mean performance and (b) comparing final mean performance to oral and written probe rates administered immediately after completion of each phase

Long-term effects were evaluated in two ways, (a) by comparing percentage change in oral and written performance from pretest to maintenance test for 20 facts assigned to oral rehearsal and 20 facts assigned to written rehearsal and (b) by comparing the combined oral and written response scores in maintenance testing for 20 facts assigned to oral rehearsal to 20 facts assigned to written rehearsal

Participants were asked to state their preference for rehearsal strategy and reasons for preference at the end of each phase of the study and at the conclusion of the study Preference for rehearsal strategy was compared to performance for each participant

Two terms were used to differentiate effects Consistent effects occur when the pattern of probe rates is similar across both phases of oral or written rehearsal (e.g., oral probe rates are faster than expected in both oral phases) Inconsistent effects occur when there is an inconsistent pattern of probe rates across both phases of oral or written rehearsal (e g , oral probe rate is faster than expected in one oral phase and slower than expected in second oral phase)

Participant One

For participant one (P1) the order of experimental phases consisted of oral-written-oral-written. Oral and written probes were administered at the end of each of the four phases. Data were collected using pre-, post-, and maintenance tests for 20 non automatic facts assigned to oral rehearsal and for 20 nonautomatic facts assigned to written rehearsal. Data on preference for rehearsal strategy were obtained at the end of each phase and at the conclusion of the study.

Graphic displays of data from rehearsal phases and from pre-, post-, and maintenance tests are presented in Figures 4-1 and 4-2, respectively. Tables 4-1 through 4-3 contain summaries of data pertaining to P1. Interobserver agreement was calculated in 20% of rehearsal sessions and 25% of pre-, post-, and maintenance tests. Interobserver agreement was 100% for rehearsal sessions and 100% for pre-, post-, and maintenance tests.

Oral Rehearsal on Oral Fluency

Data presented in Figures 4-1 and 4-2 and Tables 4-1 and 4-2 display decreases in oral response rates in first and second oral phases by 30% and 55%, respectively. Oral probe rates were 2 and 4 seconds faster than the final oral mean.

Oral Rehearsal on Written Fluency

Screening procedures for P1 yielded an oral tool skill score 1.3 times faster than written tool skill score (Table 3-1). An expected written probe rate was calculated by dividing the final oral mean response rate by 1.3. Both written probe rates were 4 seconds faster than expected.

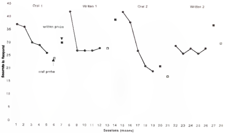

Figure 4-1 Participant 1 rehearsal sessions (means) and probes

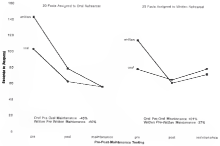

Figure 4-2 Participant 1 pre-post-maintenance test results

Table 4.1

Comparison of Final Mean Performance to Oral and Written Probes (in seconds)

Phase 1 Oral	Participant 1	Participant 2	Participant 4
Final Oral Mean	26	24	14
Oral Probe	24	25	15
Oral/Written Tool Rate	1.3	1.3	4.2
Expected Written Probe	34	31	59
Written Probe	30	33	24
Phase 2 Written			
Final Written Mean	28	23	18
Written Probe	39	21	19
Oral/Written Tool Rate	1.3	1.3	4.2
Expected Oral Probe	22	18	4
Oral Probe	28	23	15
Phase 3 Oral			
Final Oral Mean	19	19	20
Oral Probe	17	17	20
Oral/Written Tool Rate	1.3	1.3	4.2
Expected Written Probe	25	25	84
Written Probe	21	30	23
Phase 4 Written			
Final Written Mean	28	29	23
Written Probe	37	32	22
Oral/Written Tool Rate	1.3	1.3	4.2
Expected Oral Probe	22	22	5
Oral Probe	30	26	20

Table 4-1—continued

Phase 1 Written	Participant 3	Participant 5	Participant 6
Final Written Mean	16	18	14
Written Probe	19	21	16
Oral/Written Tool Rate	1.3	2.4	1.4
Expected Oral Probe	12	8	10
Oral Probe	13	16	9
Phase 2 Oral			
Final Oral Mean	11	21	18
Oral Probe	9	14	13
Oral/Written Tool Rate	1.3	2.4	1.4
Expected Written Probe	14	50	25
Written Probe	12	25	16
Phase 3 Written			
Final Written Mean	23	24	24
Written Probe	16	25	20
Oral/Written Tool Rate	1.3	2.4	1.4
Expected Oral Probe	18	10	17
Oral Probe	12	28	30
Phase 4 Oral			
Final Oral Mean	9	19	16
Oral Probe	10	16	16
Oral/Written Tool Rate	1.3	2.4	1.4
Expected Written Probe	12	46	22
Written Probe	11	26	21

Table 4-2

Percentage Change in Performance from Initial Mean to Final Mean Within Each Phase

Participant Number	Phase 1 Initial Final Mean	Percent-age Change	Phase 2 Initial Final Mean	Percent age Change	Phase 3 Initial-Final Mean	Percent age Change	Phase 4 Initial Final Mean	Percent age Change
1	37-26	30%	42-28	33%	42-19	55%	29-28	-03%
2	31-24	-23%	38-23	39%	30-19	37%	39-29	26%
3	35-16	54%	22-11	50%	23-23	0%	21-9	57%
4	19-14	-26%	21-18	-14%	21-20	-05%	20-23	+15%
5	50-18	-64%	49-21	57%	92-24	-74%	42-19	-55%
6	43-14	-67%	29-18	38%	35-24	-31%	26-16	38%

- percentage decrease
\+ percentage increase

Table 4-3

Error Rate During Oral Rehearsals, Written Rehearsals, and Maintenance Testing

Participant Number	Oral Rehearsals Number of Errors	Oral Rehearsals Error Rate	Written Rehearsals Number of Errors	Written Rehearsals Error Rate	Maintenance Testing for 20 Facts Assigned to Oral Rehearsal Error Rate	Maintenance Testing for 20 Facts Assigned to Written Rehearsal Error Rate
1	22	4%	7	1%	5%	10%
2	12	2%	27	5%	5%	5%
3	11	2%	39	8%	5%	5%
4	5	1%	13	3%	0%	0%
5	9	2%	15	3%	15%	5%
6	3	1%	7	1%	0%	5%

Written Rehearsal on Written Fluency

Data presented in Figures 4-1 and 4-2 and Tables 4-1 and 4-2 display decreases in written response rates in first and second written phases by 33% and 3% respectively. Written probe rates were 11 and 9 seconds slower than the final written mean.

Written Rehearsal on Oral Fluency

Screening procedures for P1 yielded an oral tool skill score 1.3 times faster than written tool skill score (Table 3-1). An expected oral probe rate was calculated by multiplying the final written mean response rate by 1.3. Oral probe rates were 6 and 8 seconds slower than expected.

Accuracy

P1's error rate for facts assigned to oral rehearsals was 4%. P1's error rate for facts assigned to written rehearsals was 1%. Error rates in maintenance testing were 5% for 20 facts assigned to oral rehearsal and 10% for 20 facts assigned to written rehearsal (Table 4-3).

Effectiveness

Analyses of data in Tables 4-1 and 4-2 indicate positive short term effects of oral rehearsal. Oral rehearsal decreased oral response rates. In addition, oral rehearsal produced oral probe rates faster than the final oral mean. Oral rehearsal also produced written probe rates faster than expected. Although written rehearsal decreased written response rates, oral and written probe rates were slower than expected given initial tool skills data.

Analyses of pre- post- and maintenance test data indicate positive long term effects of oral rehearsal (Figure 4-2). Oral rehearsal decreased oral response rate by 45% and decreased written response rate by 60%. Written rehearsal decreased written response rate by 37% but oral response rate increased by 1%. The combined oral and written scores on maintenance tests for 20 facts assigned to oral rehearsal were 25% faster than the combined oral and written scores on maintenance tests for 20 facts assigned to written rehearsal.

For P1 positive short term effects of oral rehearsal were observed. Analyses of data indicate that oral rehearsal produced positive effects on oral and written performance. Positive long term effects of oral rehearsal were observed in maintenance testing. P1 obtained faster combined oral and written scores on maintenance tests and lower error rates for 20 facts assigned to oral rehearsal than for 20 facts assigned to written rehearsal.

At the conclusion of the study P1 preferred oral rehearsal. According to P1 oral rehearsal produced faster response rates and was less boring than written rehearsal. Analyses of data support P1's preference. P1's performance was more consistent when oral rehearsal was used regardless of response format.

Participant Two

For participant two (P2) the order of experimental phases consisted of oral-written-oral-written. Oral and written probes were administered at the end of each of the four phases. Data were collected using pre- post- and maintenance tests for 20 non-automatic facts assigned to oral rehearsal and for 20 nonautomatic facts assigned to

written rehearsal. Data on preference for rehearsal strategy were obtained at the end of each phase and at the conclusion of the study.

Graphic displays of data from rehearsal phases and from pre-, post-, and maintenance tests are presented in Figures 4-3 and 4-4, respectively. Tables 4-1 through 4-3 contain summaries of data pertaining to P2. Interobserver agreement was calculated in 20% of rehearsal sessions and 25% of pre-, post-, and maintenance tests. Interobserver agreement was 100% for rehearsal sessions and 100% for pre-, post-, and maintenance tests.

Oral Rehearsal on Oral Fluency

Data presented in Figures 4-3 and 4-4 and Tables 4-1 and 4-2 display decreases in oral response rates in first and second oral phases by 23% and 37%, respectively. Oral probe rates were 1 second slower than the final oral mean in the first oral phase and 2 seconds faster than the final oral mean in the second oral phase.

Oral Rehearsal on Written Fluency

Screening procedures for P2 yielded an oral tool skill score 1.3 times faster than written tool skill score (Table 3-1). An expected written probe rate was calculated by dividing the final oral mean response rate by 1.3. Written probe rates were 2 and 5 seconds slower than expected.

Written Rehearsal on Written Fluency

Data presented in Figures 4-3 and 4-4 and Tables 4-1 and 4-2 display decreases in written response rates in first and second written phases by 39% and 26%, respectively.

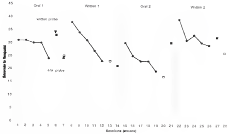

Figure 4-3 Participant 2 rehearsal sessions (means) and probes

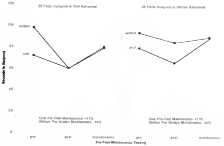

Figure 4-4 Participant 2 pre post-maintenance test results

Written probe rates were 2 seconds faster than the final written mean in the first written phase and 3 seconds slower than the final written mean in the second written phase

Written Rehearsal on Oral Fluency

Screening procedures for P2 yielded an oral tool skill score 1.3 times faster than written tool skill score (Table 3-1) An expected oral probe rate was calculated by multiplying the final written mean response rate by 1.3 Oral probe rates were 5 and 4 seconds slower than expected.

Accuracy

P2's error rate for facts assigned to oral rehearsals was 2%. P2's error rate for facts assigned to written rehearsals was 5% Error rates in maintenance testing were 5% for the 20 facts assigned to each rehearsal strategy (Table 4-3)

Effectiveness

Through analyses of data in Tables 4-1 and 4-2, it was determined that there were inconsistent patterns of short-term effects of both oral and written rehearsal Although both strategies decreased response rates during rehearsal sessions probe data display inconsistent patterns of effect given initial tool skills data.

Analyses of pre-, post-, and maintenance data indicate similar long-term effects of oral and written rehearsal (Figure 4-4) Both rehearsal strategies decreased written response rates and increased oral response rates from pre- to maintenance tests Oral rehearsal decreased written response rate by 19% and increased oral response rate by 11% Written rehearsal decreased written response rate by 5% and decreased oral

response rate by 11% The combined oral and written scores on maintenance tests for 20 facts assigned to oral rehearsal were 10% faster than the combined oral and written scores on maintenance tests for 20 facts assigned to written rehearsal

For P2 oral and written rehearsal produced similar short-term and long-term effects Both rehearsal strategies decreased response rates during rehearsal sessions and both strategies produced inconsistent short-term effects P2 obtained faster combined oral and written scores on maintenance tests for 20 facts assigned to oral rehearsal than for 20 facts assigned to written rehearsal

At the conclusion of the study P2 did not prefer one rehearsal strategy to the other According to P2, both rehearsal strategies were fun and his scores improved either way Analyses of data support P2's preference for either rehearsal strategy P2's performance was similar across both rehearsal strategies regardless of response format

Participant Three

For participant three (P3) the order of experimental phases consisted of written-oral-written-oral Oral and written probes were administered at the end of each of the four phases. Data were collected using pre- post-, and maintenance tests for 20 non automatic facts assigned to oral rehearsal and for 20 nonautomatic facts assigned to written rehearsal Data on preference for rehearsal strategy were obtained at the end of each phase and at the conclusion of the study

Graphic displays of data from rehearsal phases and from pre- post- and maintenance tests are presented in Figures 4-5 and 4-6 respectively Tables 4 1 through 4 3 contain summaries of data pertaining to P3 Interobserver agreement was calculated in 20% of rehearsal sessions and 25% of pre post and maintenance tests Interobserver

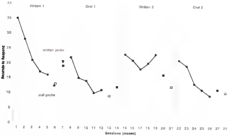

Figure 4-5 Participant 3 rehearsal sessions (means) and probes

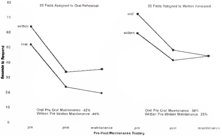

Figure 4-6 Participant 3 pre post maintenance test results

agreement was 100% for rehearsal sessions and 100% for pre post and maintenance tests

Oral Rehearsal on Oral Fluency

Data presented in Figures 4-5 and 4-6 and Tables 4-1 and 4-2 display decreases in oral response rates in first and second oral phases by 50% and 57% respectively. Oral probe rates were 2 seconds faster than the final oral mean in the first oral phase and 1 second slower than the final oral mean in the second oral phase.

Oral Rehearsal on Written Fluency

Screening procedures for P3 yielded an oral tool skill score 1.3 times faster than written tool skill score (Table 3-1). An expected written probe rate was calculated by dividing the final oral mean response rate by 1.3. Written probe rates were 2 seconds and 1 second faster than expected.

Written Rehearsal on Written Fluency

Data presented in Figures 4-5 and 4-6 and Tables 4-1 and 4-2 display decreases in written response rates in first and second written phases by 54% and 0% respectively. Written probe rates were 3 seconds slower than the final written mean in the first written phase and 7 seconds faster than the final written mean in the second written phase.

Written Rehearsal on Oral Fluency

Screening procedures for P3 yielded an oral tool skill score 1.3 times faster than written tool skill score (Table 3-1). An expected oral probe rate was calculated by multiplying the final written mean response rate by 1.3. Oral probe rates were 1 second

slower than expected in the first written phase and 6 seconds faster than expected in the second written phase

Accuracy

P3's error rate for facts assigned to oral rehearsals was 2%. P3's error rate for facts assigned to written rehearsals was 8%. Error rates in maintenance testing were 5% for the 20 facts assigned to each rehearsal strategy (Table 4 3)

Effectiveness

Through analyses of data in Tables 4-1 and 4 2, it was determined that there were inconsistent patterns of short-term effects of oral and written rehearsal. Although oral rehearsal decreased response rates during rehearsal sessions, probe data display inconsistent patterns of oral probe rates. In addition oral rehearsal produced faster written probe rates than expected given initial tool skills data.

Written response rates decreased during the first written phase but increased during the last half of rehearsal sessions in the second written phase. Probe data display inconsistent patterns of oral and written probe rates given initial tool skills data.

Analyses of pre-, post- and maintenance test data indicate positive long term effects of oral and written rehearsal (Figure 4-6). Both rehearsal strategies decreased response rates from pre- to maintenance tests. Oral rehearsal decreased oral response rate by 62% and decreased written response rate by 44%. Written rehearsal decreased oral response rate by 38% and decreased written response rate by 25%. Oral rehearsal produced greater long term effects than written rehearsal. The combined oral and written scores on maintenance tests for 20 facts assigned to oral rehearsal were 38% faster than

the combined oral and written scores on maintenance tests for 20 facts assigned to written rehearsal

For P3 analyses of data support the findings of more consistent decreases in response rates during oral rehearsal phases than written rehearsal phases Oral rehearsal also produced positive short term effects on written probe rates For P3, data in the second written phase are atypical The experimenter observed that P3 was upset for several days during the second written phase because he repeatedly discussed a failing grade that had prevented him from obtaining membership in a school club The possibility exists that this intervening event may have contributed to atypical performance in the second written phase

At the conclusion of the study P3 preferred oral rehearsal According to P3 oral rehearsal was more fun and faster Written rehearsal hurt his fingers Analyses of data support P3's preference P3's performance was more consistent using oral rehearsal

Participant Four

For participant four (P4) the order of experimental phases consisted of oral written-oral-written Oral and written probes were administered at the end of each of the four phases Data were collected using pre post and maintenance tests for 20 non-automatic facts assigned to oral rehearsal and for 20 nonautomatic facts assigned to written rehearsal Data on preference for rehearsal strategy were obtained at the end of each phase and at the conclusion of the study

Graphic displays of data from rehearsal phases and from pre post and maintenance tests are presented in Figures 4-7 and 4-8 respectively Tables 4-1 through 4-3 contain summaries of data pertaining to P4 Interobserver agreement was calculated

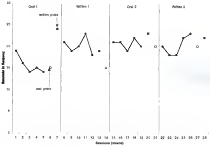

Figure 4-7 Participant 4 rehearsal sessions (means) and probes

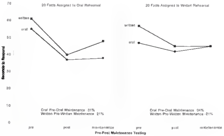

Figure 4-8 Participant 4 pre-post-maintenance test results

in 20% of rehearsal sessions and 25% of pre-, post-, and maintenance tests. Interobserver agreement was 100% for rehearsal sessions and 100% for pre-, post-, and maintenance tests.

Oral Rehearsal on Oral Fluency

Data presented in Figures 4-7 and 4-8 and Tables 4-1 and 4-2 display decreases in oral response rate in first and second oral phases by 26% and 5 %, respectively. Oral probe rates were 1 second slower than the final oral mean in the first oral phase and equal to the final oral mean in the second oral phase.

Oral Rehearsal on Written Fluency

Screening procedures for P4 yielded an oral tool skill score 4.2 times faster than written tool skill score (Table 3-1). An expected written probe rate was calculated by dividing the final oral mean response rate by 4.2. Written probe rates were 2.5 and 3.7 times faster than expected.

Written Rehearsal on Written Fluency

Data presented in Figures 4-7 and 4-8 and Tables 4-1 and 4-2 display a decrease in written response rate of 14% in the first written phase and an increase in written response rate of 15% in the second written phase. Written probe rates were 1 second slower than the final written mean in the first written phase and 1 second faster than the final written mean in the second written phase.

Written Rehearsal on Oral Fluency

Screening procedures for P4 yielded an oral tool skill score [illegible] times faster than written tool skill score (Table 3-1). An expected oral probe rate was calculated by multiplying the final written mean response rate by 4.2. Oral probe rates were [illegible] and 1.4 times slower than expected.

Accuracy

P4's error rate for facts assigned to oral rehearsals was 1%. P4's error rate for facts assigned to written rehearsals was 3%. Error rates in maintenance testing were 0% for the 20 facts assigned to each rehearsal strategy (Table 4-3).

Effectiveness

Through analyses of data in Tables 4-1 and 4-2, it was determined that both rehearsal strategies produced inconsistent patterns of response rates and probe rates across most of the phases given initial tool skills data. Oral rehearsal did produce positive short term effects for written probe rates.

Analyses of pre-, post-, and maintenance test data indicate that both oral and written rehearsal strategies decreased written response rates equally (21%). Oral rehearsal produced a greater decrease in oral response rate (31%) than written rehearsal (4%). Oral and written rehearsal produced similar long term effects in maintenance testing. The combined oral and written scores on maintenance tests for 20 facts assigned to oral rehearsal were 4% faster than the combined oral and written scores on maintenance tests for 20 facts assigned to written rehearsal.

For P4 oral and written rehearsal produced similar long-term effects. Although oral rehearsal produced positive short-term effects for written response rates, it did not produce similar long-term effects for written response rates. Oral rehearsal produced combined oral and written scores on maintenance tests that were 4% faster than the combined oral and written scores on maintenance tests for written rehearsal.

At the conclusion of the study, P4 did not prefer one rehearsal strategy to the other. According to P4, both rehearsal strategies were fun because scores decreased. Analyses of data support P4's preference for either rehearsal strategy. P4's performance was similar across both rehearsal strategies regardless of response format.

Participant Five

For participant five (P5) the order of experimental phases consisted of written-oral written-oral. Oral and written probes were administered at the end of each of the four phases. Data were collected using pre-, post- and maintenance tests for 20 non automatic facts assigned to oral rehearsal and for 20 nonautomatic facts assigned to written rehearsal. Data on preference for rehearsal strategy were obtained at the end of each phase and at the conclusion of the study.

Graphic displays of data from rehearsal phases and from pre-, post-, and maintenance tests are presented in Figures 4-9 and 4-10, respectively. Tables 4-1 through 4-3 contain summaries of data pertaining to P5. Interobserver agreement was calculated in 20% of rehearsal sessions and 25% of pre-, post-, and maintenance tests. Interobserver agreement was 100% for rehearsal sessions and 100% for pre-, post-, and maintenance tests.

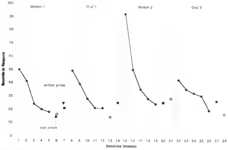

Figure 4.9 Participant 5 rehearsal sessions (means) and probes

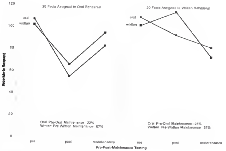

Figure 4.10 Participant 5 pre-post-maintenance test results

Oral Rehearsal on Oral Fluency

Data presented in Figures 4-9 and 4-10 and Tables 4-1 and 4-2 display decreases in oral response rates in first and second oral phases by 57% and 55%, respectively. Oral probe rates were 7 and 3 seconds faster than the final oral mean.

Oral Rehearsal on Written Fluency

Screening procedures for P5 yielded an oral tool skill score 2.4 times faster than written tool skill score (Table 3-1). An expected written probe rate was calculated by dividing the final oral mean response rate by 2.4. Written probe rates were 1.8 and 2.0 times faster than expected.

Written Rehearsal on Written Fluency

Data presented in Figures 4-9 and 4-10 and Tables 4-1 and 4-2 display decreases in written response rates in first and second written phases by 64% and 74%, respectively. Written probe rates were 3 seconds and 1 second slower than the final written mean.

Written Rehearsal on Oral Fluency

Screening procedures for P5 yielded an oral tool skill score 2.4 times faster than written tool skill score (Table 3-1). An expected oral probe rate was calculated by multiplying the final written mean response rate by 2.4. Oral probe rates were 2.0 and 2.8 times slower than expected.

Accuracy

P5's error rate for facts assigned to oral rehearsals was 2%. P5's error rate for facts assigned to written rehearsals was 3%. Error rates in maintenance testing were 1% for 20 facts assigned to oral rehearsal and 5% for 20 facts assigned to written rehearsal (Table 4-3).

Effectiveness

Through analyses of data in Tables 4-1 and 4-2, it was determined that there were positive short-term effects of oral rehearsal. Oral rehearsal decreased oral response rates. In addition, oral rehearsal produced oral probe rates faster than the final oral mean. Oral rehearsal also produced written probe rates faster than expected given initial tool skills data. Although written rehearsal decreased written response rates, oral and written probe rates were slower than expected.

Analyses of pre-, post-, and maintenance test data indicate greater long-term effects of written rehearsal. Oral rehearsal decreased oral response rate by 22%, and decreased written response rate by 7%. Written rehearsal decreased oral response rate by 25% and decreased written response rate by 28%. The combined oral and written scores on maintenance tests for 20 facts assigned to written rehearsal were 13% faster than the combined oral and written scores on maintenance tests for 20 facts assigned to oral rehearsal.

For P5, short-term positive effects of oral rehearsal were observed. Oral rehearsal produced positive effects on oral and written performance. Written rehearsal produced greater long-term effects and lower error rates than oral rehearsal.

At the conclusion of the study, P5 did not prefer one rehearsal strategy to the other. According to P5, oral rehearsal produced faster response rates, but she also liked seeing her answers in written rehearsal. Analyses of data support this position. For P5 oral rehearsal produced positive short-term effects while written rehearsal produced greater long-term effects.

Participant Six

For participant six (P6) the order of experimental phases consisted of written-oral written-oral. Oral and written probes were administered at the end of each of the four phases. Data were collected using pre-, post-, and maintenance tests for 20 non automatic facts assigned to oral rehearsal and for 20 nonautomatic facts assigned to written rehearsal. Data on preference for rehearsal strategy were obtained at the end of each phase and at the conclusion of the study.

Graphic displays of data from rehearsal phases and from pre-, post-, and maintenance tests are presented in Figures 4-11 and 4-12, respectively. Tables 4-1 through 4-3 contain summaries of data pertaining to P6. Interobserver agreement was calculated in 20% of rehearsal sessions and 25% of pre-, post-, and maintenance tests. Interobserver agreement was 100% for rehearsal sessions and 100% for pre-, post-, and maintenance tests.

Oral Rehearsal on Oral Fluency

Data presented in Figures 4-11 and 4-12 and Tables 4-1 and 4-2 display decreases in oral response rates of 38% in both oral phases. Oral probe rates were equal to and 5 seconds faster than the final oral mean

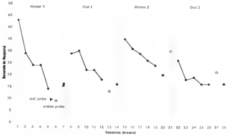

Figure 4-11 Participant 6 rehearsal sessions (means) and probes.

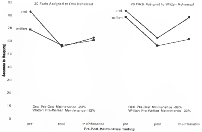

Figure 4.12 Participant 6 pre-post maintenance test results

Oral Rehearsal on Written Fluency

Screening procedures for P6 yielded an oral tool skill score 1.4 times faster than written tool skill score (Table 3-1). An expected written probe rate was calculated by dividing the final oral mean response rate by 1.4. Written probe rates were 9 seconds and 1 second faster than expected.

Written Rehearsal on Written Fluency

Data presented in Figures 4-11 and 4-12 and Tables 4-1 and 4-2 display decreases in written response rates in first and second written phases by 67% and 31% respectively. Written probe rates were 2 seconds slower than the final written mean in the first written phase and 4 seconds faster than the final written mean in the second written phase.

Written Rehearsal on Oral Fluency

Screening procedures for P6 yielded an oral tool skill score 1.4 times faster than written tool skill score (Table 3-1). An expected oral probe rate was calculated by multiplying the final written mean response rate by 1.4. Oral probe rates were 1 second faster than expected in the first written phase and 1.8 times slower than expected in the second written phase.

Accuracy

P6's error rates for facts assigned to oral rehearsals and written rehearsals were 1%. Error rates in maintenance testing were 0% for 20 facts assigned to oral rehearsal and 5% for 20 facts assigned to written rehearsal (Table 4-3).

Effectiveness

Through analyses of data in Tables 4-1 and 4-2 it was determined that there were positive short-term effects of oral rehearsal Oral rehearsal decreased oral response rates In addition oral rehearsal produced oral probe rates equal to or faster than the final oral mean. Oral rehearsal also produced written probe rates faster than expected given initial tool skills data. Although written rehearsal decreased written response rates oral and written probe rates display inconsistent patterns of effect

Analyses of pre- post-, and maintenance test data indicate greater long term effects of oral rehearsal Oral rehearsal decreased oral response rate by 24% and decreased written response rate by 12% Written rehearsal decreased oral response rate by 6% and written response rate by 22%. The combined oral and written scores on maintenance tests for 20 facts assigned to oral rehearsal were 12% faster than the combined oral and written scores on maintenance tests for 20 facts assigned to written rehearsal

For P6 oral rehearsal produced positive short-term effects and greater long term effects In maintenance testing P6 obtained an error rate of 0% for facts assigned to oral rehearsal compared to a 5% error rate for facts assigned to written rehearsal.

P6 preferred oral rehearsal in the first half of the study because response times were faster After she lost her place during an oral session she changed her preference to written rehearsal Analyses of data do not support her stated preference for written rehearsal as her performance using oral rehearsal was more consistent regardless of response format.

Summary

The purposes of this investigation were to test the validity of an instance theory of automatization on a meaningful educational task and to investigate the efficacy of oral and written rehearsal strategies on retrieval of information. A concrete task, knowledge of basic subtraction facts, was used and tested on a group of six middle school students with math disabilities based in a school environment. All students were slower than expected on recall of subtraction facts in terms of rate and accuracy data identified in the literature.

Also of interest were participants' preferences for rehearsal strategy. The relationship of stated preference to performance was evaluated for each participant.

Two research questions addressed the effectiveness of oral and written rehearsal strategies on short-term retrieval of basic subtraction facts by middle school students with math disabilities. The third research question addressed the effectiveness of oral and written rehearsal strategies on long-term retrieval. The fourth research question addressed the relationship of preference to performance.

According to instance theorists (Logan & Klapp, 1991), method of learning or instruction should have little effect on performance as long as two crucial variables are observed: (a) the nature of the exposures to stimuli is the same for all participants and (b) the number of exposures to stimuli is the same for all participants. In this investigation, all participants were exposed to the same kind of stimuli and received the same number of exposures to stimuli across all four phases of the study. Instance theorists predicted that analyses of data would demonstrate that oral and written rehearsal strategies produce similar patterns of performance.

Short-Term Retrieval

Short term effects of oral rehearsal on oral fluency were determined by (a) calculating percentage change from initial oral mean to final oral mean in each oral phase and (b) comparing final oral mean to oral probe rate in each oral phase. During oral rehearsals, all six participants' timed response rates decreased from initial oral mean to final oral mean. Amount of decrease in timed response rates varied, ranging from a 5% decrease (P3) to a 57% decrease (P5). There were consistent positive effects of oral rehearsal on oral fluency for three participants (P1, P5, and P6). Inconsistent effects were observed for participants two, three, and four.

Short-term effects of oral rehearsal on written fluency were determined by comparing an expected written probe rate calculated from initial tool skills data to written probe rate in each oral phase. There were consistent positive effects of oral rehearsal on written fluency for five participants (P1, P3, P4, P5, and P6). There was no positive effect for P2.

Short-term effects of written rehearsal on written fluency were determined by (a) calculating percentage change from initial written mean to final written mean in each written phase and (b) comparing final written mean to written probe rate in each written phase. During written rehearsals, four participants' timed response rates decreased from initial written mean to final written mean (P1, P2, P5, and P6). The amount of decrease in timed response rates varied, ranging from a 3% decrease (P1) to a 74% decrease (P5). P3's timed response rate remained the same, and the time required for P4 increased by 15%. There were no consistent positive effects of written rehearsal on written fluency for

any participant Inconsistent effects were observed for P2 P3 P4 and P6 There were no positive effects for P1 and P5

Short-term effects of written rehearsal on oral fluency were determined by comparing an expected oral probe rate calculated from initial tool skills data to oral probe rate in each written phase Inconsistent effects of written rehearsal on oral fluency were observed for two participants (P3 and P6) No positive effects were observed for P1 P2 P4 and P5

Through analyses of data, it was determined that oral rehearsal produced more positive effects on short-term retrieval of basic subtraction facts than written rehearsal Oral rehearsal produced consistent positive effects on oral fluency for three participants (P1 P5 and P6) and consistent positive effects on written fluency for five participants (P1 P3 P4 P5 and P6) There were no consistent positive effects of written rehearsal on oral or written fluency for any of the participants

Long-Term Retrieval

Long-term effects were determined in two ways First, analyses of data were used to compare percentage change of oral and written performance from pretest to maintenance test for 20 facts assigned to oral rehearsal to 20 facts assigned to written rehearsal Second, analyses of data were used to compare the oral and written response scores in maintenance testing for 20 facts assigned to oral rehearsal to the oral and written response scores in maintenance testing for 20 facts assigned to written rehearsal

Both oral and written rehearsal produced decreases in timed response rates from pretest to maintenance test for most participants Oral rehearsal decreased both written and oral timed response rates for five participants (P1 P3 P4 P5 and P6) Written

rehearsal decreased both written and oral timed response rates for four participants (P P4, P5, and P6)

Analyses of oral and written scores in maintenance tests indicate that oral rehearsal produced greater long-term effects than written rehearsal for five participants (P1 P2, P3 P4, and P6) although magnitude of effect varied across participants Magnitude of effect of oral rehearsal ranged from 4% (P4) to 38% (P3).

Preference

Preference for rehearsal strategy was addressed at the end of each of the four phases and at the conclusion of the study Two participants (P1 and P3) preferred oral rehearsal Oral rehearsal produced positive short-term and long term effects for P1 and positive long term effects for P3 During maintenance testing oral and written scores for 20 facts assigned to oral rehearsal were 25% and 38% faster than oral and written scores for 20 facts assigned to written rehearsal for P1 and P3 respectively

Three participants (P2, P4 and P5) did not prefer one rehearsal strategy to the other Oral rehearsal produced positive long-term effects for P2 and P4 but the percentage difference between rehearsal strategies was smaller (10% and 4%, respectively) than those of P1 and P3 For P5 who did not prefer one strategy to the other written rehearsal produced a greater long term effect in maintenance testing During maintenance testing, P5 s oral and written scores for 20 facts assigned to written rehearsal were 13% faster than oral and written scores for 20 facts assigned to oral rehearsal

P6 initially preferred oral rehearsal Oral rehearsal produced positive short-term effects After a frustrating oral session where she lost her place on the line of problems,

P6 changed her preference to written strategy Long-term effects of oral rehearsal were greater than long-term effects of written rehearsal for P6 Analyses of time and accuracy data do not support P6 s change in preference since there was a discrepancy between stated preference and performance

The two participants who preferred oral rehearsal were also the two participants whose oral and written scores on maintenance tests showed the largest percentage difference between the 20 facts assigned to oral rehearsal and the 20 facts assigned to written rehearsal For the three participants who did not prefer one strategy to the other their oral and written scores on maintenance tests showed smaller percentage differences between the 20 facts assigned to oral rehearsal and the 20 facts assigned to written rehearsal The participants may not have been able to discern the smaller differences in performance, and this may explain why one rehearsal strategy was not preferred to the other

In this study two methods of learning oral and written rehearsal were used to test the validity of an instance theory of automatization Instance theorists (Logan & Klapp 1991) predicted that method of learning would have little effect on performance if the nature and number of stimuli remained equal for participants For these six participants oral and written rehearsals were effective strategies for decreasing timed response rates on groups of subtraction facts Both rehearsal strategies produced similar patterns of performance for most participants

CHAPTER 5
SUMMARY AND CONCLUSIONS

A review of the study is presented in this chapter. Five major sections are presented. First, a review of the purpose, literature, and method is addressed. Second, a summary and analysis of results related to the research questions are included. Third, practical implications are discussed. Fourth, limitations of the present research are presented. Fifth, suggestions for future research conclude this chapter.

Review of Purpose, Literature, and Methods

Review of Purpose

The purpose of the study was to test the validity of an instance theory of automatization by investigating the effects of two rehearsal strategies on retrieval of basic subtraction facts by middle school students with math disabilities. According to instance theorists (Logan & Klapp, 1991), method of learning, or instruction, should have little effect on performance as long as two crucial variables are observed: (a) the nature of exposures to stimuli is the same for all participants and (b) the number of exposures to stimuli is the same for all participants. In this study, oral and written rehearsal of basic subtraction facts were used as method of learning, or instruction, to test the validity of an instance theory of automatization. Two research questions addressed the effectiveness of oral and written rehearsal strategies on short-term retrieval. The third research question

addressed the effectiveness of oral and written rehearsal strategies on long term retrieval. The fourth research question addressed the relationship of preference to performance.

Review of Literature

In the area of mathematics, many local, state and national education agencies have reported performance deficits in the area of computation by students in elementary and secondary settings. Fluency in computational skills received major emphasis by the National Council of Teachers of Mathematics (NCTM) in Principles and Standards for School Mathematics (2000). The NCTM recommended that all students in PreK-2 develop fluency in addition and subtraction facts through 10 and that all students in grades 3 through 5 develop fluency in all basic arithmetic facts.

Memory researchers have contributed knowledge of rehearsal strategies that lead to automatic, or fluent, performance. Automatic or fluent performance is the result of a transition from algorithmic processing to memory-based processing. Numerous researchers have demonstrated that rehearsal strategies such as semantic encoding, categorizing, sorting, verbal rehearsal, and cumulative rehearsal increased recall of items by children of all ages (Keraston & Flavell, 1979; Ornstein, Naus, & Liberty, 1975). Researchers also found that instructing children on the value of rehearsal strategies, as well as providing feedback, significantly improved performance (Kennedy & Miller, 1976; Lacher, 1983).

Researchers have demonstrated that fluent performance of basic math facts is a determiner of success within a mathematics curriculum (Binder, 1996; Johnson & Layng, 1992). Fluency building strategies produce several positive educational outcomes: (a) fluency increases retention and maintenance of knowledge (Berquam, 1981; Kelly,

1996) (b) fluency increases on task performance (Binder 1984 LaBerge & Samuels 1974) and (c) fluency supports a more rapid learning of higher level skills (Johnson & Layng 1994) Fluency-based interventions have been shown to be effective with general or mild disability populations, severe populations and adult learners (Johnson & Layng 1992, Lindsley 1992, Pollard 1979)

Mathematics researchers have suggested fluency rates for basic arithmetic facts Suggested fluency rates varied considerably across studies. Suggested fluency rates for basic subtraction facts ranged from 40-60 written digits per minute (Starlin & Starlin, 1973) to 70-90 written digits per minute recommended by the Precision Teaching Project in the 1970s.

Mathematics researchers have also suggested teaching strategies for successful drill and practice Effective drill and practice require both a readiness level on the part of the learner and specific teacher behaviors Children must be able to demonstrate knowledge of the underlying concepts of number properties, addition, and subtraction before initiation of drill (Davis, 1978, Driscoll 1990) Specific teacher behaviors to increase fluency include adhering to intensive daily practice, keeping accurate records praising student effort, and informing the student of the value of the strategy (Davis 1978, Driscoll 1990 Good & Grouws, 1979 Moely Hart Leal, Santulli Rao Johnson & Hamilton 1992)

Instance theorists suggest that automaticity or fluency is the consequence of drill because practice provides opportunities to respond to stimuli Instance theory relates automaticity or fluency to the memory component of attention. Performance is automatic when it is based on single step direct access retrieval of past solutions to

memory Logan (1988) stated that novice learners begin with a general algorithm that is sufficient to perform a task In acquisition of simple arithmetic facts the general algorithm would be one of several counting strategies (Carpenter & Moser 1984) As learners gain experience (instances) they learn specific solutions to specific problems, which they retrieve when they encounter the same problems again (Ashcraft 1982) At some point, learners gain enough experience to respond with a solution from memory At that point, performance is automatic or fluent

In a series of experiments, Logan and Klapp (1991) determined that method of learning had little effect on performance as long as participants received the same kind of stimuli and the same number of stimuli. Logan and Klapp predicted that different rehearsal strategies would show similar patterns of performance as long as instances to respond to presentations of stimuli remained equal in nature and number

There are serious gaps in memory and rehearsal strategy research as they pertain to retrieval of basic math facts. First, over 90% of relevant studies in memory strategy research focused on age correlated differences (Schneider & Sodian, 1997) There is a scarcity of research examining the effect of rehearsal strategies within age groups Second, few researchers have investigated the effects of rehearsal strategies on single item retrieval tasks such as basic arithmetic facts. The majority of rehearsal strategy research has been conducted on recall of serial or unrelated items Third, memory research has not been extended to educationally relevant tasks in natural settings. Fourth memory research has not been extended to include participants with disabilities

There are also serious gaps in mathematics research as they pertain to retrieval of basic math facts. First, mathematics researchers seldom conduct their investigations

within theoretical frameworks of memory Second, there is considerable variability in suggested rates for fluency of basic math facts Third while there are empirical data to support written rehearsal as an effective strategy there is little evidence that other rehearsal strategies have been attempted or validated Fourth researchers have not investigated either the number of rehearsals or the proportion of instructional time necessary to retain basic math facts in memory

Researchers have demonstrated that automatic or fluent, performance of basic math facts is a determiner of success within a mathematics curriculum Practitioners need research-based best practices in fluency building that can be successfully incorporated within existing mathematics curricula and that can be successfully implemented for children as usual learning events and for children with learning problems This investigation of rehearsal strategies on retrieval of basic subtraction facts by middle school children with math disabilities adds to knowledge of the relationship between rehearsal strategy and memory retrieval.

Review of Methods

The study investigated the effectiveness of two rehearsal strategies on retrieval of basic subtraction facts by middle school students with math disabilities Oral and written rehearsal were the methods of learning, or instruction, used to test the validity of an instance theory of automatization (Logan, 1988)

The participants included six middle school students who were eligible for special education service in mathematics Three females and three males participated There were two sixth graders, three seventh graders, and one eighth grader Five participants were 12 years old and one was 13

To participate in the study each student had to meet 10 criteria. In addition each participant was screened for initial oral (saying numbers) and written (writing numbers) tool skills, absence of automaticity on 40 subtraction facts, and knowledge of subtraction concepts.

An ABAB comparison of treatment design (Kazdin, 1982) was used to test an instance theory of automatization and to compare the effectiveness of oral and written rehearsal strategies. The study consisted of four phases for each participant. Three participants were randomly assigned to oral-written-oral-written condition. Three participants were randomly assigned to written-oral-written-oral condition.

Each phase of each condition contained 10 basic subtraction facts that were randomly distributed from 40 nonautomatic facts identified by screening procedures. Each participant had five rehearsal sessions per day on the same ten facts. Each phase had 25 rehearsal sessions. After the 25th session oral and written probes of the 10 facts were administered.

In addition, each participant was administered a pretest, posttest, and maintenance test for the 20 facts assigned to oral rehearsal and for the 20 facts assigned to written rehearsal. Maintenance tests were administered 2 weeks after the conclusion of all four phases.

The dependent variables across all phases and tests were timed response rate and accuracy. Method of rehearsal (oral or written) was the independent variable. In addition participants' preference for rehearsal strategy was assessed at the end of each phase and at the conclusion of the study.

Summary and Analysis of Results

Two research questions addressed the effectiveness of oral and written rehearsal strategies on short term retrieval of basic subtraction facts by middle school students with math disabilities. The third research question addressed the effectiveness of oral and written rehearsal strategies on long term retrieval. The fourth research question addressed the relationship of stated preference to performance.

In the first two questions, the effects of oral and written rehearsal strategies on short term retrieval of subtraction facts were addressed to determine the effect of (a) oral rehearsal on oral fluency, (b) oral rehearsal on written fluency, (c) written rehearsal on oral fluency, and (d) written rehearsal on written fluency. Oral rehearsal produced consistent positive effects on oral fluency for three participants. Oral rehearsal also produced consistent positive effects on written fluency for five participants. There were no consistent positive effects of written rehearsal on oral or written fluency for any of the participants.

In the third question, the effects of oral and written rehearsal strategies on long term retrieval of subtraction facts were determined by (a) comparing the percentage change of oral and written performance from pretest to maintenance test for each participant for the 20 facts assigned to oral rehearsal to the 20 facts assigned to written rehearsal and (b) comparing the oral and written scores in maintenance testing for 20 facts assigned to oral rehearsal to the oral and written scores in maintenance testing for 20 facts assigned to written rehearsal. Oral and written rehearsal strategies produced similar results concerning response rates from pretest to maintenance tests. Oral

rehearsal decreased both written and oral response rates for five participants. Written rehearsal decreased both written and oral response rates for four participants.

Analyses of oral and written scores in maintenance tests indicate that oral rehearsal produced greater long term effects for five participants. The magnitude of effect of oral rehearsal varied across the five participants, ranging from oral and written scores for 20 facts assigned to oral rehearsal that were 4% to 38% faster than oral and written scores for 20 facts assigned to written rehearsal.

Written rehearsal produced a greater long-term effect for one participant. The oral and written scores in maintenance tests for 20 facts assigned to written rehearsal were 13% faster than the oral and written scores for the 20 facts assigned to oral rehearsal.

The fourth question addressed the relationship of stated preference to performance. Two participants preferred oral rehearsal and three participants did not prefer one strategy to the other. One participant initially preferred oral rehearsal but changed her preference to written rehearsal midway in the study.

The two participants who preferred oral rehearsal were also the two participants whose oral and written scores in maintenance testing showed the largest magnitudes of effect of oral rehearsal. The three participants who did not prefer one strategy to the other had smaller magnitudes of effect of either oral or written rehearsal. The one participant's preference for written rehearsal was not supported by performance data.

Discussion and Implications

The results of this investigation of the effects of oral and written rehearsal strategies on retrieval of subtraction facts have implications for mathematics instruction

for middle school students with math disabilities related to (a) individualized instruction and (b) instructional efficiency.

Individualized Instruction

In previous research, written rehearsal was found to be an effective strategy for increasing fluency of basic facts (Bender, 1993; Johnson & Layng, 1992). For the six participants in this investigation, oral rehearsal was also found to be an effective rehearsal strategy for retrieval of subtraction facts. The middle school students who participated in this study were able to benefit from both oral and written rehearsal strategies, although analyses of results show that oral rehearsal was a more effective strategy than written rehearsal for most participants.

In addition, all six participants had positive comments about oral rehearsal, even if they did not prefer one rehearsal strategy to the other. There are several possible explanations for these positive comments. First, several of the students described the writing process as slow or hurtful. Oral practice may have provided the needed practice while eliminating the unpleasant task of writing. Second, oral rehearsal allowed students to talk while learning. The oral component of oral rehearsal may have been motivating in and of itself. Third, because the students could say numbers faster than writing them, oral rehearsal generally produced faster final response rates than written rehearsal. For the participants, the faster final response rates in oral rehearsal may have been a motivating factor.

Individualizing instruction for remediation of skills involves careful selection of strategies that produce the largest effect of treatment. Strategies that motivate student

participation and learning should be incorporated into individualized instruction to maximize effect of learning

Instructional Efficiency

Proponents of fluency building programs proposed that the majority of instructional time should be allotted to fluency training (Johnson & Layng, 1994). In this investigation, six participants spent approximately 15 minutes, or 20%, of their instructional time in mathematics rehearsing subtraction facts. Each of the four phases per participant lasted 5 days. In 10 of the 24 phases, timed response rate was faster by 23% to 39%. In 9 of the 24 phases, timed response rate was faster by 50% to 74%. Based on the results of this study, a small percentage of instructional time devoted to rehearsal can produce positive results for building fluency in subtraction facts for middle school students with a diagnosed math disability.

In addition, oral rehearsal is more cost effective than written rehearsal. Written rehearsal requires either multiple practice sheets per day or the use of laminated sheets that require cleaning after each rehearsal along with the cost of marking utensils specifically designed for laminated materials. Oral rehearsal requires only two practice sheets, one for the participant and one for the observer. Oral rehearsal allows repeated use of the materials with no interruptions for cleaning or the expense of writing utensils. Because there are no interruptions for cleaning laminated materials or switching practice sheets, more instructional time in oral rehearsal sessions can be devoted to practice which translates into more practice per rehearsal session or less instructional time needed to practice a given number of facts.

In summary, analyses of results indicated that oral and written rehearsals were effective rehearsal strategies for retrieval of subtraction facts by middle school students with learning disabilities in mathematics. Two participants preferred oral rehearsal, and all six participants had positive comments about oral rehearsal. Oral rehearsal was more cost effective and time efficient than written rehearsal. The present findings support the suggestion that instructional personnel consider oral rehearsal as an additional instructional strategy for retrieval of basic subtraction facts.

Limitations in the Present Study

There were several limitations in the present study that may affect results and should be considered when interpreting data. First, none of the participants achieved written proficiency levels for subtraction facts suggested by previous researchers during any of the phases of the investigation. It is unknown if results for these participants would be affected if the investigation had continued until suggested fluency levels had been obtained. Second, the results were limited by subject selection. It is unknown if results for these participants could be replicated with other students sharing similar characteristics or with students in other populations or educational settings. Third, the investigator was the sole instructor during the study. It is unknown if the results of the investigation were a function of one behavior change agent. Fourth, all instruction for the participants was conducted on an individual basis in a setting that was relatively free from distractions. It is unknown if the results would be affected if instruction was provided in a group setting or in the general classroom environment.

Future Research

Further research is needed to determine the utility of oral rehearsal as a primary instructional strategy for retrieval of basic subtraction facts. Future research should include testing the validity of instance theory as it relates to (a) automaticity of all basic facts (b) effectiveness of oral and written rehearsal strategies with students from different populations and in different instructional settings, and (c) replication of results in studies using experimental group designs

Further research is needed to determine the utility of rehearsal strategies as they relate to (a) the relationship of oral and written tool skills to automaticity (b) analyses of number of presentations needed for automaticity for facts and families of facts with students from different populations and in different instructional settings, (c) analyses of number of presentations needed for automaticity of basic facts for children as an initial learning event and for children with learning problems, and (d) analyses of the amount of instructional time needed to achieve fluent behavior with students from different populations and in different instructional settings

APPENDIX A
PERMISSION FORMS

UNIVERSITY OF FLORIDA INSTITUTIONAL REVIEW BOARD

1. **TITLE OF PROTOCOL**: The efficacy of two rehearsal strategies and their impact on retrieval in students with learning disabilities in mathematics

2. **PRINCIPAL INVESTIGATOR(s)**: Mary Ann Nelson, M Ed
Department of Special Education
Norman G315
University of Florida
(352) 392-0701 ext 248
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3. **SUPERVISOR (IF PI IS STUDENT)**: Mary Kay Dykes Ph D
Department of Special Education
Norman G315
University of Florida
(352) 392-0701
mkdykes@coe.ufl.edu
FAX (352) 392 2655

4. **DATES OF PROPOSED PROTOCOL**: From January 3, 2001 To June 3 2001

5. **SOURCE OF FUNDING FOR THE PROTOCOL**: None

6. **SCIENTIFIC PURPOSE OF THE INVESTIGATION**: The purpose is two-fold (a) to test the efficacy of oral and written practice on the acquisition of basic subtraction facts with middle school students with learning disabilities and (2) to test an instance theory of automatization

7. **DESCRIBE THE RESEARCH METHODOLOGY IN NON-TECHNICAL LANGUAGE**: Six middle school children with learning disabilities will be selected to participate in a study that examines the effectiveness of written and oral practice on the acquisition of basic subtraction facts Each child will have 40 individually selected facts to learn by groups of ten One week the child will practice ten facts orally with the investigator The next week the child will practice ten facts with the examiner by writing the answer The process will

repeat for two more weeks, one week using oral practice and the other week using written practice The total practice time is four weeks The practice sessions will take about 10 minutes per day and will take place during the regularly scheduled mathematics period for each child Progress will be measured by timing the student on each practice session and by assessing the accuracy of the answers Corrective feedback will be given to the student after each session At the conclusion of the study, the students will be asked their preference for practice

8. **POTENTIAL BENEFITS AND ANTICIPATED RISK** There are no anticipated risks for the participants in the study There are several potential benefits for the participants in the study (a) the participant's performance on basic subtraction facts will improve (b) the participants will have knowledge of two rehearsal strategies to use in future study tasks; (c) the teacher of the participants will gain knowledge of the effectiveness of two rehearsal strategies for future instructional interventions and (d) because the participants are currently receiving educational services for students with learning disabilities the results from participation will help in the formulation of short term and long-term goals in mathematics instruction for the individual educational plan (IEP) required annually for students receiving special education services

9 **DESCRIBE HOW PARTICIPANT(S) WILL BE RECRUITED, THE NUMBER AND AGE OF THE PARTICIPANTS, AND PROPOSED COMPENSATION (if any)** There will be no compensation for participants in the study Participants will be recruited from a middle school special education program in Alachua County upon approval for the study from the director of research for Alachua County Schools The students will be enrolled part time in special education classes that serve students with disabilities in grades six through eight, ages 10 through 14 Special education teachers responsible for mathematics instruction for students with learning disabilities will be asked to submit names of students who exhibit poor recall speed or accuracy of basic subtraction facts. A parent information letter will be sent home and a parent informed consent form will be signed for each participant if the parent wishes the child to participate in the study After receiving the signed parent permission forms the investigator will explain the purpose of the study to the student and will read the student assent form to each student The student will sign the assent form if he/she wishes to participate in the study

10 **DESCRIBE THE INFORMED CONSENT PROCESS. INCLUDE A COPY OF THE INFORMED CONSENT DOCUMENT (if applicable)** There are three steps in the informed consent process (a) the parent will receive a parent information letter describing the study (b) the parent will receive a parent informed consent form to sign if he/she wishes his/her child to participate in the study and (c) if the parent agrees to participation for his/her child the investigator will discuss the purpose of the study to each student. The

investigator will read the child assent form to each student and ask the child to sign if he/she wishes to participate (see attached forms)

Principal Investigator's Signature ______________________ **date**______

Supervisor's Signature_________________________________**date**______

I approve this protocol for submission to the UFIRB:

____ **date**______

Dept. Chair/ Center Director

Parent Information Letter

Dear Parents

I am a teacher in the Alachua County School System and a doctoral student in the Department of Special Education at the University of Florida. My supervisor is Dr Mary Kay Dykes, Professor of Special Education at the University of Florida. As part of my dissertation research I am studying mathematics computation for middle school students with learning disabilities.

Participants in this study will be asked to practice subtraction facts. They will participate in oral and written practice of ten facts each day for about ten minutes per day during their math class. They will practice different groups of facts for about four weeks. Their performance will be timed in each session, and the answers will be corrected and discussed with each student. At the end of the study, they will be asked which form of practice they liked better. It is believed that this training will improve their subtraction skills and the results will help their teachers plan future mathematics instruction for them.

Specifically, I am asking for your permission to (a) include your child in this project, and (b) obtain descriptive information about your child from school records (sex, grade, ethnicity, age, history of retention (if any), history of truancy (if any), intelligence quotient, eligibility for assisted lunch program, math achievement scores).

A number will be assigned to each participant to maintain the confidentiality of the information. There will be no audio or video tape recording of the practice sessions. Your child's privacy will be protected to the fullest extent of the law.

Participation in this study is voluntary. Nonparticipation will not affect your child's grade or special education service. There are no foreseen risks to your child by his/her participation in the study. You have the right to withdraw permission for your child's participation at any time during the study. Your child has the right to withdraw from the project at any time. He/she may choose not to answer questions on practice preference. No monetary or other compensations will result from participation in the study.

If you have any questions or concerns about participants' rights, you may contact the UFIRB office, Box 112250, University of Florida, Gainesville, FL 32611-2250. If you have any questions or concerns about any aspect of the project, you may reach me at the Department of Special Education, University of Florida, Gainesville, FL 32611, (352) 392-0701, ext. 248, or maryann462@aol.com. You may contact my supervisor, Dr. Mary Kay Dykes, at the Department of Special Education, University of Florida, Gainesville, FL 32611, (352) 392-0701, or mkdykes@coe.ufl.edu.

Sincerely,

Mary Ann Nelson, M Ed
Principal Investigator

Parent Informed Consent

I have read the procedure for this project described in the p[illegible] letter. I give permission for my child, ______________________________

(a) to participate in this study of the acquisition of basic subtraction facts for middle school students with learning disabilities (b) to allow the principal investigator Mary Ann Nelson to obtain descriptive information about my child from school records.

I have read and I understand the description of my child's participation in the project and have received a copy of this description. I understand that all information will remain confidential with respect to the identity of my child. I understand that I may withdraw consent for my child's participation at any time. I understand that my child may withdraw from the project at any time. I understand that there is no compensation for participation in the study and that there are no foreseen risks to my child as a result of his/her participation.

Signatures:

Parent/Guardian ______________________________ date__________

Parent/Guardian ______________________________ date__________

Principal Investigator ___________________________ date__________

Supervisor ________________________________ date__________

Department Chair _____________________________ date__________

Child Assent Form

Name ____________________

Teacher____________________

Project Location____________________

It has been explained to me that I have the opportunity to learn subtraction facts. I would like to participate in this project. I understand that my scores will be recorded for the amount of time I take to practice the facts in each session and for the number of facts I answer correctly.

I understand that my identity will be kept confidential and a number will be used on records instead of my name. I understand that I do not receive any gifts for participation. I understand that I can withdraw from participating at any time and that I do not have to answer any questions. I understand that there are no foreseen risks to me for my participation.

Signatures:

Student ____________________ date__________

Teacher ____________________ date__________

Principal Investigator ____________________ date__________

Supervisor ____________________ date__________

Department Chair ____________________ date__________

APPENDIX B
INSTRUCTIONAL MATERIALS

Name_________________________________ Participant #____

Eligibility Requirements

_____ 1 Meets state of Florida definition of specific learning disability
_____ 2 Demonstrated disability in mathematics
_____ 3 Enrolled in special education classes part of the school day for mathematics instruction.
_____ 4 Is not enrolled in any other special education programs
_____ 5 Normal intelligence
_____ 6 Deficient in speed _____ accuracy _____ or recall _____ of subtraction facts
_____ 7 Does not have a history of absenteeism
_____ 8 Has not been retained more than once
_____ 9 Signed parent consent.
____ 10 Signed child assent

Demographics

_____ 1 Gender
_____ 2 Age
_____ 3 Grade
_____ 4 Ethnicity
_____ 5 Assisted lunch program
_____ 6 Special Education classification
_____ 7 General ability score.
_____ 8 Individual measure of achievement in mathematics
Date __________
Test __________
Score

Score(s)____

Screening

_____ 1 Demonstrates a solution to a fact problem using manipulatives or fingers
_____ 2 Draws a representation of a solution to a fact problem using paper and pencil
_____ 3 Orally produces a simple story problem using a subtraction fact
_____ 4 Applies a strategy for subtraction within a multi-step problem
_____ 5 Number of non-automatic *facts from nine* ________ / 33
_____ 6 Number of non-automatic *facts from eighteen* ________ / 39
_____ 7 One minute probe of writing numerals 0-9
Number of responses ______ / minute
_____ 8 One minute probe of saying numerals 0-9
Number of responses ______ / minute

Pretests

_____ 1 Oral pretest of 20 oral condition facts Rate ______ Accuracy ______
_____ 2 Written pretest of 20 oral condition facts Rate ______ Accuracy ______
_____ 3 Oral pretest of 20 written condition facts Rate ______ Accuracy ______
_____ 4 Written pretest of 20 written condition facts Rate ______ Accuracy ______

Directions for Daily Rehearsal

1. Today we are going to practice some subtraction facts. Before we begin, how are you feeling? Is everything going OK for you today? Are you ready to begin practicing your ten subtraction facts?
2. Remember that we are practicing the ten facts by ________________________ (writing the answer or saying the answer)
3. In a minute, I will put a sheet of paper in front of you. Today we will be starting our practice on row # ________. When I say "begin now" you will call out or write the answers as fast as you can. I will be timing you with this stopwatch. Work as fast as you can and don't skip any answers. Are you ready?
4. Point to row. Say, "begin now."
5. That was super (great, terrific, well done, etc.). You missed _____ problem(s). The correct answer to ___ - ____ is _____.
6. Are you ready to begin again? We will now practise row # _______. Say "begin now."

The experiment will repeat directions 5 and 6 until five rows have been completed.

7. We have finished our practice sessions for today. Thank you for working so hard. I will see you tomorrow (or Monday if over a weekend) and we will be practicing our ten facts again.

Preference Data Sheet

Participant _____

Phase 1 _____________
Do you like to practice your facts this way?

What do you like or dislike about practicing this way?

Phase 2 _____________
Do you like to practice your facts this way?

What do you like or dislike about practicing this way?

Phase 3 _____________
Do you like to practice your facts this way?

What do you like or dislike about practicing this way?

Phase 4 _____________
Do you like to practice your facts this way?

What do you like or dislike about practicing this way?

Now that you have completed all the practice sessions, did you like to practice in a certain way?

Individual Data Sheet

Participant _____
Phase _____
Rehearsal _____

Session	Time	Correct	Incorrect	Session	Time	Correct	Incorrect
1				21			
2				22			
3				23			
4				24			
5				25			
6				26			
7				27			
8				28			
9				29			
10				30			
11				31			
12				32			
13				33			
14				34			
15				35			
16				36			
17				37			
18				38			
19				39			
20				40			
Oral Probe				Written Probe			

Anecdotal Comments:

Pretest/Posttest/Maintenance Probe Data Sheet

Participant________

Pretest	Oral Time	Correct	Incorrect	Written Time	Correct	Incorrect
20 Oral Facts						
20 Written Facts						
Posttest	Oral Time	Correct	Incorrect	Written Time	Correct	Incorrect
20 Oral Facts						
20 Written Facts						
Maintenance Probe	Oral Time	Correct	Incorrect	Written Time	Correct	Incorrect
20 Oral Facts						
20 Written Facts						

When I say BEGIN, say these numbers as fast as you can

1	5	9	7	3	4	6	0	2	3
8	4	2	4	6	8	0	1	3	5
7	9	0	1	4	7	2	5	8	3
6	9	8	5	2	1	3	4	6	7
9	0	1	5	9	2	6	3	4	8
7	1	2	3	7	8	9	6	5	4
1	7	9	3	4	8	6	2	0	1
2	5	4	7	8	9	8	6	7	3
2	0	1	4	7	8	5	2	0	[illegible]
6	9	8	4	5	7	6	3	2	1
1	5	9	7	3	4	6	0	2	5
8	4	2	4	6	8	0	1	3	5
7	9	0	1	4	7	2	5	8	3
6	9	8	5	2	1	3	4	6	7
9	0	1	5	9	2	6	3	4	8

(150)

Screening *Subtraction-From-18*

11 -2	12 -4	13 -6	14 -8	10 -9	12 -8	10 -6	13 -5
11 -3	14 -9	12 -7	11 -4	12 -9	10 -4	16 -9	14 -6
11 -8	15 -7	13 -9	12 -5	10 -2	13 -8	16 -7	11 -5
12 -3	11 -6	13 -7	11 -9	10 -8	15 -6	10 -7	17 -8
10 -3	14 -5	11 -7	15 -9	13 -4	15 -8	17 -9	

Screening *Subtraction-From-9*

9	8	7	4	8	6	5	8
-9	-7	-5	-4	-3	-2	-5	-6
6	9	3	8	6	9	7	5
-4	-3	-2	-8	-6	-5	-4	-3
8	5	8	9	7	9	4	2
-2	-2	-5	-8	-6	-4	-3	-2
7	7	9	5	9	7	6	9
-7	-2	-6	-4	-2	-3	-5	-7
3							
-3							

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BIOGRAPHICAL SKETCH

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She began her doctoral program at the University of Florida as a full-time student in 1999. Her major areas of study included the educational needs of children with mild disabilities and gifted children. She has accepted a position at Georgia Southern University to begin in August 2001.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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